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The United States' European Phased Adaptive Approach Missile Defense System

Defending Against Iranian Threats Without Diluting the Russian Deterrent

Jaganath Sankaran

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Preface

The European Phased Adaptive Approach (EPAA) missile defense system was initiated by the Barack Obama administration in 2009 to defend against current and future missile threats posed by Iran to bases and cities in Europe. The plan, however, garnered strong opposition from Russia. In particular, Phase 4 of the system, in which Standard Missile (SM)-3 IIB would be deployed in Redzikowo, Poland, was cited by Russia as a threat to its nuclear deterrent. After the New Strategic Arms Reduction Treaty was signed in 2010, Russia refused to engage in further nuclear arms control talks with the United States unless its concerns about EPAA were addressed. In March of 2013, Phase 4 of the EPAA system was canceled. Analysis in this report shows that the restructured system does not affect Russia's deterrent and is still capable of kinematically reaching and intercepting Iranian missiles. This policy action has opened a window for the United States and Russia to come together on additional bilateral nuclear arms reduction measures and missile defense cooperation.

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The author of this report thanks colleagues and reviewers for their input and improvements to the report; any remaining errors or omissions, however, are the sole responsibility of the author. Comments are welcome and may be addressed to jaganath.sankaran@gmail.com.

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Summary

In October 2009, the Barack Obama administration announced the deployment of a missile defense system, the European Phased Adaptive Approach (EPAA), that was based on the Standard Missile (SM)-3 (IB, IIA, and IIB variants) deployed on Aegis missile defense ships in the Mediterranean Sea and at Aegis Ashore land sites later slated for Deveselu, Romania, and Redzikowo, Poland.[1] The EPAA system was conceived to defend against present and future Iranian missile threats to U.S. bases in Europe and to North Atlantic Treaty Organization (NATO) member and allied nation cities.

The plans for EPAA, however, were also seen as an effort to address Russian concerns about U.S. missile defense plans. The previous George W. Bush administration had opted to extend the Ground-Based Mid-Course Defense (GMD) missile defense system—which was already deployed in Alaska and California—to Europe to defend against Iranian missile threats. The Russians viewed this GMD system in Europe as a threat to their strategic deterrent. The plan for EPAA thus led to severe strains in U.S.-Russian relations and to a pause in bilateral nuclear arms reduction.[2]

In 2009, the then–newly elected Obama administration reached out to Russia with a "reset" in relations. The administration decided to cancel the previously planned GMD system and replace it with the EPAA missile defense system. This was viewed by some as an indirect policy action meant to mitigate Russian concerns about the GMD system. Russia initially reacted positively to this gesture.[3]

However, as details emerged on the EPAA missile defense system, Russian officials began to express concern that Phase 4 of the EPAA system—in which SM-3 IIB interceptors (with a burnout velocity of 5.5 km/s)[4] would be deployed at Redzikowo—would be able to intercept their intercontinental ballistic missiles (ICBMs). Some of them also claimed that EPAA Aegis missile defense ships deployed in the North Sea and Barents Sea would be able to kinematically

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[1] "Remarks by the President on Strengthening Missile Defense in Europe," White House Office of the Press Secretary, September 17, 2009; Arms Control Association, "The European Phased Adaptive Approach at a Glance," Washington, D.C., May 2013.

[2] Ken Dilanian, "Obama Scraps Bush Missile-Defense Plan," *USA Today*, 2009; Massimo Calabresi, "Behind Bush's Missile Defense Push," *Time*, June 5, 2007.

[3] Jill Dougherty, "Clinton 'Reset Button' Gift to Russian FM Gets Lost in Translation," CNN, March 6, 2009; Kevin Whitelaw, "Obama's Missile Plan Decision: What It Means," National Public Radio, September 17, 2009.

[4] *Burnout velocity* is the maximum speed acquired by the interceptor. Simply put, the higher the speed of the interceptor, the farther it can go. Burnout velocity can, therefore, serve as a strong indicator of the EPAA missile defense system capability. Before it was canceled, the speculated burnout velocity for SM-3 IIB interceptors was between 5 km/s and 5.5 km/s. This report assumes that the value is 5.5 km/s.

reach and intercept Russian ICBMs. Russian officials vehemently opposed the deployment of Phase 4 of the EPAA system.[5]

On March 2013, the Obama administration decided to cancel Phase 4. Instead, the plan was to add more interceptors to the GMD system deployed in Alaska.[6] This policy decision, although officially citing development problems and a lack of money for developing the interceptors, addressed the principal stated Russian concern about the EPAA system without altering its primary goal of defending against Iranian missiles. To date, however, the change has not resulted in any significant shift in Russia's position on further reducing strategic nuclear arms or on desiring missile defense cooperation with NATO or the United States.

Revised EPAA Against Iran

It appears from the calculations detailed in the report that the restructured EPAA system, even after canceling the Phase 4 SM-3 IIB interceptors, might still be able to kinematic[7]ally reach and intercept Iranian missiles. The SM-3 IB missiles (with an assumed burnout velocity of 3.5 km/s) deployed on Aegis missile defense ships in the Eastern Mediterranean Sea and in Deveselu, together are able to defend against most present Iranian threats from the various types of the deployed and postulated Shahab-3 missile.

Similarly, the SM-3 IB stationed in the Mediterranean Sea and deployed at Deveselu (EPAA Phase 2) and the SM-3 IIA (with an assumed burnout velocity of 4.5 km/s[8]) deployed in Redzikowo (EPAA Phase 3) will be able to defend against future intermediate range ballistic missile threats that Iran might employ, such as a missile based on the Safir space-launch vehicle.

Revised EPAA Against Russia

The technical analysis described in this report demonstrates that the restructured EPAA system does not pose a threat to Russian ICBMs. The interceptors at Deveselu are not capable of reaching Russian ICBMs. The SM-3 IIA interceptors based at Redzikowo are able to intercept Russian ICBMs from only two of the Eastern Russian missile launch sites under an unrealistic

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[5] Robert Coalson, "European Missile Defense: What's on the Table at NATO Summit?" Radio Free Europe/Radio Library, May 19, 2012; Nuclear Threat Initiative, "Russia Warns U.S. Against Deploying Final Phases of Missile Shield," October 1, 2012b; Jim Wolf, "Exclusive: U.S. Dangles Secret Data for Russia Missile Shield Approval," Reuters, March 13, 2012; "Moscow Takes Harder Line, but NATO Chief Still 'Hopeful' on Missile Defense," Radio Free Europe/Radio Library, May 3, 2012.

[6] The addition of 14 interceptors in Alaska was justified as a response to growing North Korean missile threats. For details, see Tom Z. Collina, Daryll Kimball, and Greg Thielmann, "What Does DOD's Missile Defense Announcement Mean?" *Arms Control Now*, March 15, 2013; and Eliot Marshall, "A Midcourse Correction for U.S. Missile Defense System," *Science*, Vol. 339, March 29, 2013.

[7] Kinematic reach is the ability of the interceptor to reach the same region in space occupied by the target missile at the same time.

[8] One source that makes a similar suggestion is Arms Control Association, 2013.

zero-time-delay condition. When real-world, operational time delays are imposed, the interceptors at Redzikowo have no capability against Russian ICBMs. Similarly, interceptors launched from Aegis ships located in the North Sea and Barents Sea with real-world, operational time delays are not able to kinematically reach Russian ICBMs in time for a successful interception.

Conclusion

The policy decision taken by the Obama administration to cancel Phase 4 of the EPAA missile defense system has provided a valuable opportunity to alleviate Russian concerns about EPAA capabilities. Cancellation of that phase of the system, which was strengthened by additional political actions, should create a time window for both the United States and Russia to discuss their bilateral security concerns and nuclear arms reduction measures.

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Finally, this report would not have materialized without the determination of the Stanton Foundation to support emerging nuclear policy analysts. I thank them whole-heartedly for investing in me.

Abbreviations

BMD	Ballistic Missile Defense
EPAA	European Phased Adaptive Approach
FY	fiscal year
GBI	Ground-Based Interceptors
GMD	Ground-Based Midcourse Defense
ICBM	intercontinental ballistic missile
IRBM	intermediate range ballistic missile
NATO	North Atlantic Treaty Organization
SM-3	Standard Missile-3
START	Strategic Arms Reduction Treaty
V_{bo}	burnout velocity

1. Origin and Evolution of the European Phased Adaptive Approach

The European Phased Adaptive Approach (EPAA) missile defense system was conceived by the Barack Obama administration to defend against Iranian missile threats, both present and future. In 2009, President Obama, announcing the deployment of the EPAA missile defense system, said:

> We have updated our intelligence assessment of Iran's missile programs, which emphasizes the threat posed by Iran's short- and medium-range missiles, which are capable of reaching Europe. . . . This new approach will provide capabilities sooner, build on proven systems, and offer greater defenses against the threat of missile attack than the 2007 European missile defense program. . . . Because our approach will be phased and adaptive, we will retain the flexibility to adjust and enhance our defenses as the threat and technology continue to evolve.[9]

The 2007 European missile defense program was formulated during the George W. Bush administration. According to this program, ten Ground-Based Interceptors (GBIs) were to be based in Poland and a radar system was to be located in the Czech Republic. GBI missiles were already installed in Fort Greely, Alaska, and Vandenberg Air Force Base, California, as part of the Ground-Based Midcourse Defense (GMD) system. The Bush administration's plan was to extend it to Europe to counter possible threats from Iran to Europe and the continental United States.

Russia claimed that the Bush administration's 2007 plan for a missile defense system in Europe was a significant threat to its nuclear deterrent.[10] Russia threatened to cease all cooperative bilateral arms control measures and escalate its military posture if the system was deployed. Then, arguing against the deployment of the system, Russian President Vladamir Putin said, "If a part of the strategic nuclear potential of the United States appears in Europe and, in the opinion of our military specialists, will threaten us, then we will have to take appropriate steps in response. What kind of steps? We will have to have new targets in Europe."[11] Similarly, Russian General Nikolai Solovtsov threatened to target states in Eastern Europe that cooperated with the U.S. missile defense program. He said, "If the government of Poland, the Czech Republic, and other countries make this decision—and I think mutual consultations that have been held and will be held will allow avoiding this—the strategic missile troops will be able to have those facilities as targets. Consequences in case of hostilities will be very grave for both sides.[12]

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[9] "Remarks by the President on Strengthening Missile Defense in Europe," White House Office of the Press Secretary, September 17, 2009.

[10] Ken Dilanian, "Obama Scraps Bush Missile-Defense Plan," *USA Today*, 2009.

[11] Massimo Calabresi, "Behind Bush's Missile Defense Push," *Time*, June 5, 2007.

[12] Thom Shanker, "Moscow Perplexes U.S. Over Missile Defense in Europe," *New York Times*, February 21, 2007.

Relations between the United States and Russia were seen as considerably deteriorated in part due to the deployment of the European missile defense system.

When President Obama took office in 2009, his administration wanted to "reset" U.S. relations with Russia. Meeting with Russian Foreign Minister Sergey Lavrov in May 2009, then–U.S. Secretary of State Hillary Clinton said, "I would like to present you with a little gift that represents what President Obama and Vice President Biden and I have been saying and that is: 'We want to reset our relationship, and so we will do it together.'"[13] Ending the European component of the GMD system and replacing it with the EPAA missile defense system based on Standard Missile (SM)-3 weapons was seen as an attempt to change the dynamic of what was perceived as an increasingly tense relationship between the United States and Russia.[14] The Obama White House justified its decision by claiming to have new intelligence showing that Iran's long-range missile capabilities are not as advanced as previously believed. Instead, it intends to upgrade and deploy SM-3 interceptors that are useful mainly for intercepting short- and medium-range missiles, where, it says, Iranian capability "is developing more rapidly than previously projected."[15]

However, it should be noted that the Obama White House described the decision as a response to changing Iranian missile capabilities and not as a concession to Russia. There were, however, hopes that this decision would lead to better cooperation from Russia on numerous fronts, including the imposition of sanctions on Iran. Russia welcomed the cancellation of the Bush administration's missile defense plan in 2009. Then–Russian President Dmitry Medvedev said, "We appreciate this responsible move by the U.S. president."[16] Then–Russian Prime Minister Vladimir Putin, echoing this sentiment, said, "The latest decision by the Obama administration has positive implications. And I very much hope that this very right and brave decision will be followed by others."[17] Further, President Medvedev, indicating a more cooperative posture with U.S. concerns, said, "There always is a score in politics. And if our partners hear some of our concerns, we will, of course, be more attentive to theirs."[18] In fact, the New Strategic Arms Reduction Treaty (START) signed in April 2010 is seen as an example of a successful measure emerging from the "reset."[19] However, as details on the planned EPAA

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[13] Jill Dougherty, "Clinton 'Reset Button' Gift to Russian FM Gets Lost in Translation," CNN, March 6, 2009.

[14] Kevin Whitelaw, "Obama's Missile Plan Decision: What It Means," National Public Radio, September 17, 2009.

[15] "Obama's Missile Defense: It's Better These Days to Be a U.S. Adversary Than Its Friend," *Wall Street Journal*, September 18, 2009.

[16] Dilanian, 2009; Whitelaw, 2009.

[17] Julian E. Barnes and Megan K. Stack, "Russia's Putin Praises Obama's Missile Defense Decision," *Los Angeles Times*, September 19, 2009.

[18] Clifford J. Levy and Peter Baker, "Russia's Reaction on Missile Defense Plan Leaves Iran Issue Hanging," *New York Times*, September 18, 2009.

[19] Dave Boyer, "Obama Defends Russia 'Reset' Despite Strained Ties With Putin," *Washington Times*, September 4, 2013.

missile defense system emerged, Russian claims about the vulnerability of its strategic deterrent resurfaced.

The EPAA missile defense system was to consist of four phases, beginning in 2011 and reaching full deployment in 2022, with interceptors stationed on Aegis ships in the Mediterranean Sea and at land sites in Deveselu, Romania, and Redzikowo, Poland, to defend against a variety of current and future Iranian missile threats (see Figure 1.1). Phase 1 of the EPAA system consists of the SM-3 IA and SM-3 IB interceptors on Aegis ships in the Mediterranean Sea and a land-based radar in Turkey. In March 2011, the Aegis ship *USS Monterrey* was deployed, making the EPAA system operational. Phase 2 of the system has a planned deployment date of 2015, with the first Aegis Ashore interceptor site in Deveselu.[20] This site will host the SM-3 IB and a land-based Aegis SPY-1 radar. Phase 3 of the system has a planned deployment date around 2018 and will involve deploying the more powerful SM-3 IIA interceptors (with a burnout velocity of 4.5 km/s) at the second Aegis Ashore site in Redzikowo. Phase 3 will substantially expand the coverage that EPAA provides for European allies. Finally, Phase 4 was planned to be operational around 2022 with the SM-3 IIB interceptors (with a burnout velocity between 5 and 5.5 km/s) deployed in Poland.[21] While the total number of Aegis missile defense ships and SM-3 interceptors that would be deployed in the European theater as part of EPAA is not known, the overall projected plan is to increase the Ballistic Missile Defense (BMD)–capable ships, from 33 at the end of fiscal year (FY) 2014 to 43 at the end of FY 2019. Similarly, the total number of inventoried SM-3 interceptors is expected to increase from 144 in FY 2014 to 267 in FY 2019, with a majority being SM-3 IA and SM-3 IB interceptors.[22] All of these ships, however, will not be a part of EPAA. Some of them will operate in Asia and in other places where needs arise.

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[20] The land-based deployment of the SM-3 interceptor missiles in Deveselu and Redzikowo are generally referred to as *Aegis Ashore*.

[21] Arms Control Association, "The European Phased Adaptive Approach at a Glance," May 2013.

[22] Ronald O'Rourke, *Navy Aegis Ballistic Missile Defense (BMD) Program: Background and Issues for Congress*, Congressional Research Service, November 7, 2014.

Figure 1.1. Deployment Plans for the European Phased Adaptive Approach (EPAA) Missile Defense System

- Conceived in 2009 to defend Europe against Iranian missile threats. The EPAA is designed to adapt and respond in proportion to Iranian capabilities.
- As originally planned, EPAA consists of four phases:
  - Phase 1 consists of SM3-IA missiles with a burnout velocity (V_{bo}) of 3 km/sec loaded on Aegis ships. Phase 1 has been deployed. The missiles are meant to defend against short- and medium-range missiles.
  - Phase 2 consists of SM3-IB missiles with a V_{bo} of 3.5 km/sec deployed on Aegis ships and in Deveselu, Romania. Deployment is planned for 2015. The missiles are meant to defend against short- and medium-range missiles.
  - Phase 3 consists of SM3-IIA missiles with a V_{bo} of 4.5 km/sec deployed on Aegis ships and in Deveselu, Romania, and Redzikowo, Poland. Deployment is planned for 2018. The missiles are meant to defend against medium- and intermediate-range missiles.
  - Phase 4 consisted of SM3-IIB missiles with a V_{bo} of 5.5 km/sec deployed in Deveselu, Romania, and Redzikowo, Poland. Deployment plans for Phase 4 were canceled in 2013. The missiles were meant to defend against intermediate-range and intercontinental ballistic missiles.

SOURCE: Arms Control Association, 2013.

Russian concerns about the effects of the EPAA missile defense system on its strategic deterrent rested mostly on the capability of the fourth phase of the system involving advanced interceptors and possible space-based components.[23] In particular, it seems, Moscow fears that the system could eventually be capable of undermining its nuclear deterrent.[24] Talking at Davos for an interview in early 2013, Russian President Medvedev said, "We do not want next generations of politicians in 2019 or 2020 to take decisions which would open a new page in the arms race. But such a threat exists and everyone in Russia and the United States should understand this, that's why we still have chances to come to an agreement."[25]

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[23] Robert Coalson, "European Missile Defense: What's on the Table at NATO Summit?" Radio Free Europe/Radio Library, May 19, 2012; Nuclear Threat Initiative, "Russia Warns U.S. Against Deploying Final Phases of Missile Shield," October 1, 2012b.

[24] Jim Wolf, "Exclusive: U.S. Dangles Secret Data for Russia Missile Shield Approval," Reuters, March 13, 2012; "Moscow Takes Harder Line, but NATO Chief Still 'Hopeful' on Missile Defense," Radio Free Europe/Radio Library, May 3, 2012.

[25] "'No Flexibility' in US Missile Talk—Medvedev," Sputnik News, January 27, 2013. Such an idea to develop a complete missile defense system against Russia, though rarely considered seriously in the U.S. debate, does emerge. In a *Wall Street Journal* article on May 15, 2012, U.S. Senator Jon Kyl (R-Ariz.) said that such defenses "are

Russia has linked further bilateral nuclear arms reduction to changes in U.S. missile defense plans. Medvedev has argued that it is crucial that any antimissile system established on the continent will not "disrupt strategic stability and will not be directed against either of the sides." Speaking at the G8 Summit in 2011, Medvedev also said, "If we do not reach an agreement by 2020, a new arms race will begin."[26] Similarly, Russian President Putin said in a statement in August 2012, "Russia is open to new joint initiatives in this area [arms control]. At the same time, their realization is clearly possible only on a fair mutual basis and if all factors affecting international security and strategic stability are taken into account." Among the factors is the "unilateral and totally unlimited deployment of a global U.S. missile defense system."[27]

The early U.S. response to Russia on its claims of vulnerability has been that the EPAA does not pose a threat to Russia's missile forces. U.S. officials have repeatedly made this point, arguing that the system is designed for ballistic missile threats from outside the Euro-Atlantic area and can neither negate nor undermine Russia's strategic deterrent capabilities. In late 2011, for example, Rose Gottemoeller responded to Russian concerns by saying,

> Persistent misperceptions about the capabilities of the proposed [North Atlantic Treaty Organization (NATO)] system—specifically that the system would target Russian ICBMs [intercontinental ballistic missiles] and undermine Russia's strategic deterrent—are unfounded. We have worked at the highest level of the United States government to be transparent about our missile defense plans and capabilities and to explain that our planned missile defense programs do not threaten Russia or its security.[28]

As a mitigating measure to assuage its concerns, Russia has asked for legally binding "military-technical" guarantees from the United States and NATO that the missile defenses that they are deploying in Europe will not be aimed against Moscow's strategic nuclear forces.[29] The only publicly available explanation from Russians of what constitutes military-technical guarantees describes them as making certain changes to the algorithms of the operation of missile defense radars, refraining from bringing Aegis-equipped ships into areas that are in direct proximity to the potential trajectories of Russia's ICBMs and submarine-launched ballistic

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intended to defend chiefly against Iran but depending on future developments might be effective against Russian missiles as well." (See Coalson, 2012.)

[26] Peter Topychkanov, "Missile Defense: Not Joint, but Cooperative," Russia Beyond the Headlines, June 24, 2011.

[27] Nuclear Threat Initiative, "New Russian Nuke Cuts Will Depend on U.S. Missile Defense Moves: Putin," Washington, D.C., August 24, 2012a.

[28] Charles Hoskinson, "Gap Widens Over Missile System," *Politico*, September 14, 2011. Also see Frank R. Rose, Deputy Assistant Secretary, Bureau of Arms Control, Verification and Compliance, "Reinforcing Stability Through Missile Defense," remarks made at the Organization for Security and Co-operation in Europe's Forum for Security Co-Operation, Vienna, Austria, June 6, 2012a; Frank R. Rose, "Growing Global Cooperation on Missile Defense," address delivered at the 2012 Multinational Ballistic Missile Defense Conference and Exhibition, Berlin, Space News, October 1, 2012b.

[29] Nuclear Threat Initiative, "Russia Restates Demand for Pledge on NATO Missile Shield," September 14, 2011; Robert Bridge, "Moscow Looking for NATO Cooperation, Missile Defense Guarantees," RT News, February 19, 2013.

missiles, stationing Russian observers at U.S. and NATO missile defense installations, and formulating a mechanism to monitor the implementation of such measures.[30]

The U.S. has predictably declined to engage in any formal military-technical agreement with Russia on the EPAA missile defense system. Frank Rose argued at the Organization for Security and Co-operation in Europe's Forum for Security Co-Operation in June 2012 that Russia's demand for military-technical guarantees would create limitations on the ability of the United States to develop and deploy future missile defense systems against the evolving ballistic missile threats presented by Iran and North Korea.[31] As the growth of ballistic missile threats continues unabated, he argued, the United States cannot place artificial limits on its ability to defend itself, its allies, and its partners. This, he further added, includes any limitation in the operating areas of U.S. BMD-capable, multimission Aegis ships, which are meant to be relocated to adapt to changing regional threats and provide surge capabilities where they are most needed. The U.S. government has, however, expressed willingness to accept a political agreement that U.S. missile defenses are not aimed at Russia. According to Ellen Tauscher, Special Envoy for Strategic Stability and Missile Defense, any such statement would be politically binding and would publicly proclaim the intent of the United States to work together with Russia in charting the direction for cooperation.[32]

On March 15, 2013, the Obama administration decided to eliminate the fourth phase of the EPAA system,[33] citing development problems and a lack of money. The restructuring includes spending $1 billion to add 14 interceptors to the 26 that currently exist in Alaska under the GMD missile defense system.[34]

The now-restructured EPAA system should reassure Russians that the system does not affect their strategic deterrent. Chapters 3 and 4 of this report will provide analytical evidence to that effect. Chapter 3 will show that the restructured system is able to defend against a range of current and future Iranian missile threats. Chapter 4 will demonstrate that the restructured EPAA system does not pose a threat to Russian ICBMs. The interceptors at Deveselu are not capable of reaching Russian ICBMs. In addition, the SM-3 IIA interceptors based at Redzikowo are able to intercept Russian ICBMs from only two of the missile launch sites in Eastern Russia under an

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[30] Sergey Rogov, Viktor Yesin, Pavel Zolotarev, and Valentin Kuznetsov, "Russia: Experts—Missile Defense Compromise Dependent on Obama Reelection," World News Connection, NTIS, original Russian publication in *Nezavisimoye Voyennoye Obozreniye*, September 20, 2012.

[31] Rose, 2012a.

[32] Ellen Tauscher, U.S. Department of Defense Special Envoy for Strategic Stability and Missile Defense, "Ballistic Missile Defense: Progress and Prospects," remarks made at the Tenth Annual Missile Defense Conference, Washington D.C., March 26, 2012.

[33] Tom Z. Collina, Daryll Kimball, and Greg Thielmann, "What Does DOD's Missile Defense Announcement Mean?" *Arms Control Now*, March 15, 2013; Eliot Marshall, "A Midcourse Correction for U.S. Missile Defense System," *Science*, Vol. 339, March 29, 2013.

[34] Associated Press, "US Changes in Missile Defense Plan May Provide Opening for New Arms-Control Talks with Russia," March 17, 2013.

unrealistic zero-time-delay condition. When real-world, operational time delays are imposed, the interceptors at Redzikowo have no capability against Russian ICBMs. Similarly, interceptors launched from Aegis ships located in the North Sea and Barents Sea with real-world, operational time delays are not able to kinematically reach Russian ICBMs in time for a successful interception.

However, Russia still insists on a legal guarantee that U.S. missile defenses are not directed at it, which in turn has slowed bilateral U.S.-Russian arms-control talks.[35] Madelyn Creedon, Assistant Secretary of Defense for Global Strategic Affairs, speaking in November 2013, said, "The United States is not making much progress in arms-control and missile defense talks with Russia. It is important to have Russia's support on topics. To be frank, we're not making much progress on that front but we'll continue to try."[36] She also indicated that regardless of whether an international agreement is reached with Iran that would curb the Persian Gulf state's ability to develop a nuclear weapon, the United States is "ironclad" in its resolve to deploy next-generation interceptors in Europe under Phases 2 and 3 of the EPAA plan.[37]

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[35] Steven Pifer, "U.S.-Russian Arms Control in the Absence of a Summit," Brookings Institution, September 4, 2013.

[36] Rachel Oswald, "U.S. Official: 'Not Making Much Progress' With Russia on Missiles, Arms," Global Security Newswire, November 13, 2013.

[37] Oswald, 2013.

2. The Iranian Missile Threat

Concern over the threat posed by Iranian missiles, along with the progression of Iran's nuclear program, has been present since the early days of the Obama administration. In 2008, Obama, then a Democratic presidential candidate, called for tighter sanctions on Iran after it flight-tested nine long- and medium-range missiles as part of its Great Prophet III exercise in the strategic Strait of Hormuz. "Iran is a great threat. We have to make sure we are working with our allies to apply tightened pressure on Iran," he said.[38] In 2009, in announcing the deployment of the EPAA missile defense system to defend against Iranian missile threats, President Obama said, "We have updated our intelligence assessment of Iran's missile programs, which emphasizes the threat posed by Iran's short- and medium-range missiles, which are capable of reaching Europe. This new approach will provide capabilities sooner, build on proven systems, and offer greater defense against the threat of missile attack."[39]

These concerns over Iran's missile program have continued to surface. In February 2010, the International Atomic Energy Agency said that it had concerns about Iranian "activities related to the development of a nuclear payload for a missile."[40] According to James Clapper, Director of National Intelligence, "Iran already has the largest inventory of ballistic missiles in the Middle East, and it is expanding the scale, reach, and sophistication of its ballistic missiles forces."[41] The 2012 Department of Defense Annual Report on Military Power of Iran stated, "Iran may be technically capable of flight-testing an intercontinental ballistic missile by 2015."[42] Similarly, the joint report by the U.S. Air Force National Air and Space Intelligence Center, the Defense Intelligence Agency, and the Office of Naval Intelligence stated, "Iran could develop and test an ICBM capable of reaching the U.S. by 2015."[43] However, it is worth noting that U.S. intelligence forecasts warn about the potential for Iran to field ICBMs, if it so decided. The U.S. intelligence community does not, however, cite evidence that Iran is actively developing or building ICBMs.

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[38] Angela Balakrishnan, "Barack Obama Calls for Tougher Iran Sanctions After Missile Tests," *The Guardian*, July 9, 2008.

[39] "Remarks by the President on Strengthening Missile Defense in Europe," 2009.

[40] International Atomic Energy Agency, "Implementation of the NPT Safeguards Agreement and Relevant Provisions of Security Council Resolutions 1737 (2006), 1747 (2007), 1803 (2008) and 1835 (2008) in the Islamic Republic of Iran," GOV/2010/10, 2010, para 41.

[41] James R. Clapper, Director of National Intelligence, "Unclassified Statement for the Record on the Worldwide Threat Assessment of the U.S. Intelligence Community for the Senate Select Committee on Intelligence," Washington D.C., January 31, 2012.

[42] U.S. Department of Defense, *Annual Report on Military Power of Iran*, April 2012, p. 4.

[43] National Air and Space Intelligence Center, *Ballistic and Cruise Missile Threat*, U.S. Air Force, Wright-Patterson Air Force Base, Ohio, 2013.

To accentuate these U.S. concerns, Iran has publicly declared U.S. and allied bases and military assets in the region as potential targets. Iran has also threatened to use its missiles to attack oil refineries in the Gulf region in the event of a U.S. or Israeli strike on installations that support its nuclear program.[44] At the end of the three-day Great Prophet military exercise in July 2012, Amir Ali Haji Zadeh, commander of the elite Iranian Revolutionary Guard, told the Fars News Agency, "[U.S.] bases are all in range of our missiles, and the occupied lands [Israel] are also good target for us."[45] Similarly, after its most recent Great Prophet VIII exercise in February 2013, Iran announced that the war drills are a "message of peace and friendship to countries in the region." Tehran further stated that it felt no exterior threat apart from the United States and Israel, and that the missiles pose no threat to Europe.[46]

Iranian Missile Capability: State of Play

Iran has steadily been able to increase its technological sophistication in missiles and satellite launch vehicles, which have historically been tied to ICBM development programs. Table 2.1 provides an accounting of the capabilities of various Iranian missiles. Iran has developed at least four different liquid-propellant missiles: the Shahab-1, Shahab-2, Shahab-3, and Ghadr-1 (also referred to as Kavoshgar or Shahab-3M). These are all single-stage liquid propellant missiles. The Shahab-1 has an estimated range of about 300 km, while the Shahab-2, which apparently carries a lighter conventional warhead, has an estimated range of about 500 km. The variants of Shahab-3, based on the North Korean No Dong, have ranges from 1,500 km to 2,500 km, depending on the warhead weight. Iran has also managed to develop a solid-fueled missile, Ashura or *Sajjil*, which gives it more mobility and therefore less vulnerability to a preemptive strike compared with liquid-fueled missiles; the Ashura has an estimated range of 2,000 km.[47] In addition, Iran has successfully launched a liquid-propellant, two-stage Safir space launch vehicle, which could be used in an intermediate-range ballistic missile (IRBM) role. It has also unveiled a larger and more capable space launch vehicle called Simorgh, which is yet to be flight demonstrated.[48]

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[44] Michael Singh, "Iran Threatens Gulf Blitz If U.S. Hits Nuclear Plants," *Sunday Times*, June 10, 2007.

[45] "Iran Boasts It Could Wipe Out US Presence in Middle East in Minutes," RT News, July 4, 2012.

[46] Trend S. Isayev and T. Jafarov, "Iran to Hold 'Great Prophet VIII' Military Exercises," Trend News Agency, February 20, 2013; Paul Fiddan, "Iran's Great Prophet VIII Military Exercise," Armed Forces International, February 20, 2013.

[47] Siegfried S. Hecker and David Holloway, *Iran's Nuclear and Missile Potential: A Joint Threat Assessment by U.S. and Russian Technical Experts*, EastWest Institute, May 2009; Congressional Budget Office, *Options for Deploying Missile Defenses in Europe*, February, 2009; International Institute for Strategic Studies, "Iran's Ballistic Missile Capabilities: A Net Assessment," Strategic Dossier, May 7, 2010; Steven A. Hildrith, "Iran's Ballistic Missile and Space Launch Programs," Congressional Research Service, December 6, 2012; Paul Reynolds, "Iran's Slow but Sure Missile Advance," BBC News, February 3, 2009.

[48] Peter Crail, "Iran Launches Second Satellite," *Arms Control Today*, July/August 2011.

Table 2.1. Capabilities of Iranian Threat Missiles

	Stage	Fuel	t_{bo} (sec)	V_{bo} (km/sec)	Maximum Range (km)	Warhead (kg)
Missiles Posing a Near-Term Threat						
Shahab-3	1	Liquid	98	3.4	**1,300**	800
Shahab-3A Shahab-3M Ghadr-1	1	Liquid	98	3.7	**1,500-1,800**	500
Shahab-3B					**2,000-2,500**	500
Sajjil/Ashura	2	Solid	72	3.8	**2,000**	900
Missiles Posing a Potential Future Threat						
IRBM (Safir/ BM-25/Musudan)	2	Liquid	188	5.5	**5,200**	
Liquid-fuel ICBM	2/3	Liquid	329	7.6	**17,800**	

NOTE: These burnout times (t_{bo}) will be used later as interceptor launch time delays.

Iran's ability to threaten U.S. or allied bases in Europe depends on its Shahab-3 variants (see Figure 2.2 and Figure 2.3). However, the vast majority of Iran's ballistic missiles consists of Shahab-1 and -2, which have a short range of less than 500 km.[49] The EPAA missile defense is not designed to handle these short-range missile threats. Instead, these threats could be addressed through shorter-range defenses, such as the Patriot missile defense system. The targets of the EPAA system are the present Shahab-3 missile and future potential Iranian IRBMs that will be able to reach deeper into Europe.

[49] Hildrith, 2012.

Figure 2.1. Coverage of Notional Shahab-3A Missile (1,500 km range)

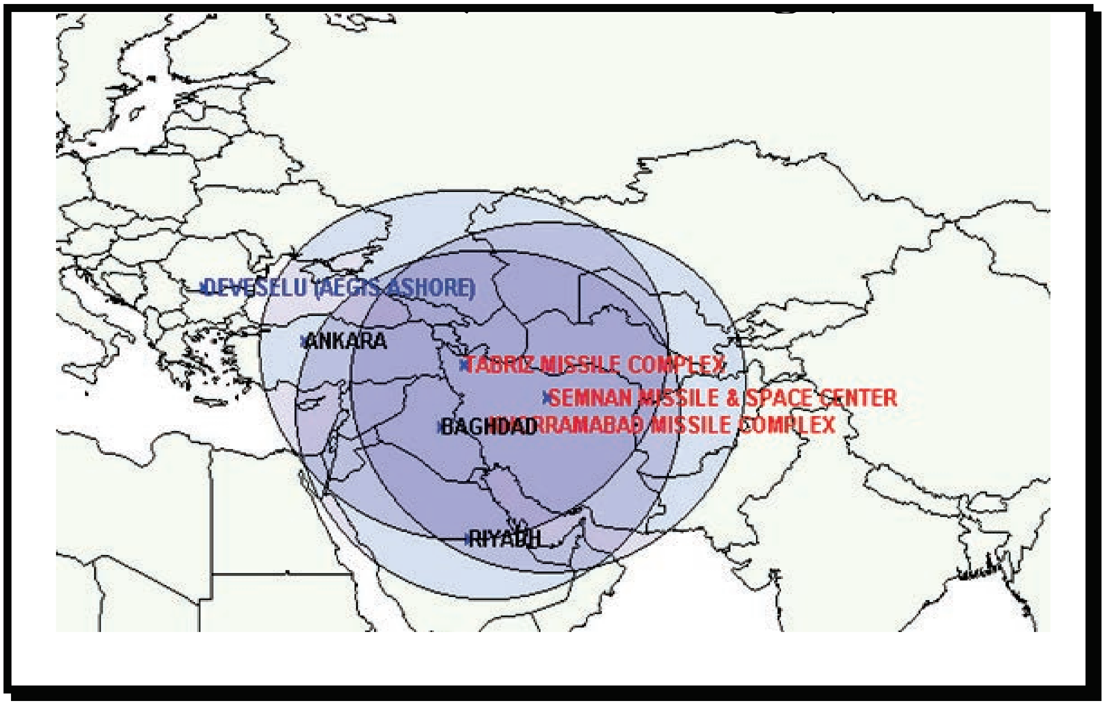
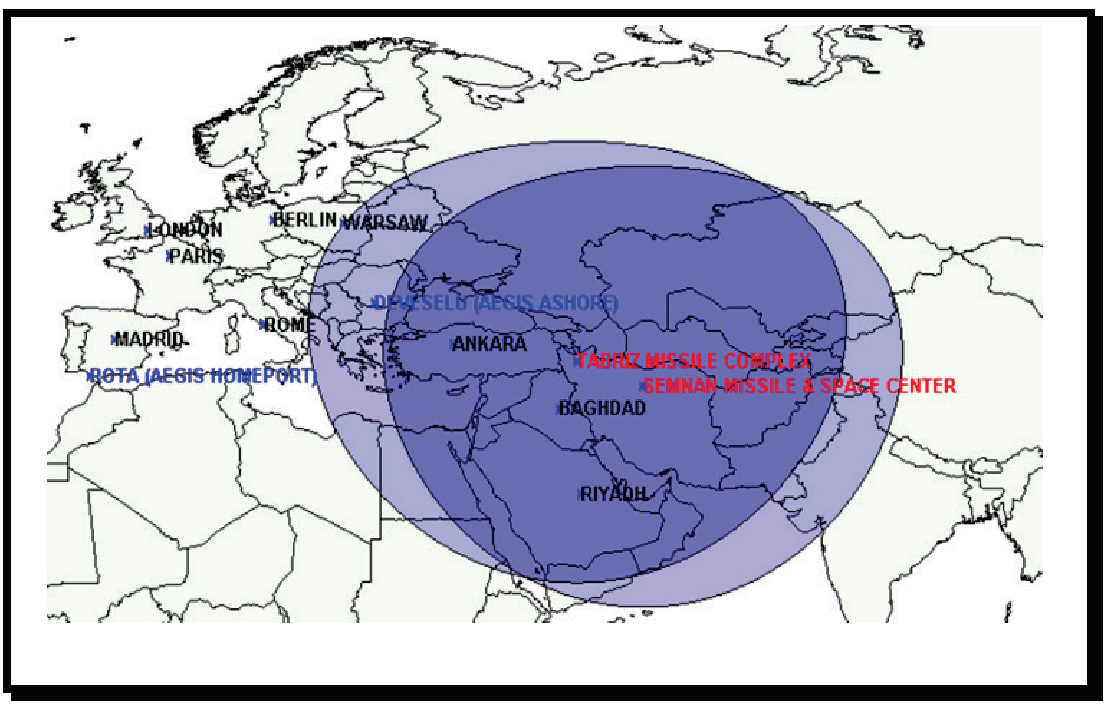


Figure 2.2. Coverage of Notional Shahah-3B Missile (2,500 km range)



Iranian Missile Capabilities: Doubts and Limits

Despite Iran's public pronouncements and publicized flight tests, assessments of Iranian missile capabilities are very speculative.[50] Part of the reason for this stems from Iranian bluster about its capabilities. For example, in 2008 after a Shahab-3 flight test, pictures released by Iranian news agencies showed more missiles that were actually fired during the test. *Agence France-Presse* retracted its version of the image, saying that it was "apparently digitally altered" by Iranian state media and that the fourth missile in the image "has been apparently retouched to cover a grounded missile that may have failed during the test."[51] Similarly, in 2006, Iran claimed a successful launch of a long-range, radar-evading ballistic missile, which was actually video of a missile launch from a Chinese submarine.[52] Steven A. Hildreth of the Congressional Research Service said, "Iran has a demonstrated history of lying, misleading, and misinforming about their missile- and space-launch tests."[53]

Most of the data of the Iranian missile program are estimates. This, in turn, leads to questions about the threat Iran projects in reality. Scholars have also raised the possibility that Iran does not have the technological sophistication to employ its missiles effectively. Itzkowitz Shifrinson and Priebe argue that Iran's capacity to disrupt Saudi Arabian oil installations is unfounded due to the limited number and accuracy of Iranian missiles.[54] Others have said that developing missiles that could strike targets throughout Europe would require either the production of large and vulnerable systems or major advances beyond the technologies Iran has so far demonstrated.[55] This report examines the effectiveness of the EPAA missile system without needing to resolve these potential limits of Iranian missile capability.

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[50] Greg Bruno, "Iran's Ballistic Missile Program," Council on Foreign Relations, July 23, 2012.

[51] Mike Nizza and Patrick J. Lyons, "In an Iranian Image, A Missile Too Many," *The New York Times*, July 10, 2008; "Iran Doctored Missile Test-Firing Photo: Defence Analyst," *The Gazette*, CanWest MediaWorks Publications, July 10,2008.

[52] "World in Brief," *The Washington Post*, September 10, 2006, p. A23.

[53] Hildreth, 2012.

[54] Joshua R. Itzkowitz Shifrinson and Miranda Priebe, "A Crude Threat: The Limits of an Iranian Missile Campaign Against Saudi Arabian Oil," International Security, Vol. 36, No. 1, Summer 2011.

[55] Hecker and Holloway, 2009.

3. The Performance of EPAA Against Iranian Threats

The main motivation in developing and deploying the EPAA missile defense system was to defend against current and future Iranian missile threats. This chapter will demonstrate that the restructured EPAA system (after the cancellation of Phase 4 SM-3 IIB interceptors) will still be able to kinematically engage all current and potential Iranian IRBM missiles. Kinematic reach, however, does not imply an intercept capability under field operational conditions. In a real-world scenario, a number of conditions will have to be met to successfully intercept a missile. First, the early-warning satellites and missile tracking radars will need to pick up the signatures of an Iranian missile launch. The analysis in this report assumes that satellites and radars will be able to observe and track the Iranian missiles. Sensitivity analysis of this assumption is left to future iterations of this work. Second, the nearest interceptor location would have to launch an interceptor toward the Iranian missile in a timely manner. Finally, the interceptor and its payload kill vehicle will need to maneuver, particularly in the endgame, to hit the target missile with sufficient closing speed.

The intercept modeling and simulation discussed in this chapter do not examine these factors. It only looks at the ability of the interceptor to reach the same region in space occupied by the target Iranian missile at the same time—that is, kinematic reach. Kinematic reach is the appropriate metric for comparing these interceptors, and that is the primary item of interest in this report.

Simulation Methodology

The methodology employed in this report, both to calculate the interceptor launch velocity needed to target a missile and to simulate the target missile and interceptor trajectories themselves, relies on Kepler's laws. In order to determine if an interceptor missile would have sufficient velocity to kinematically reach a target missile, the solution to *Lambert's problem* (also known as the rendezvous or intercept problem) derived from Kepler's laws was used. Lambert's problem uses two position vectors—the interceptor launch location and the desired intercept point—and the time of flight between them to calculate the launch velocity required.

After determining if an interceptor has sufficient launch velocity to reach the target missile, then the flight path (coordinate positions in space) of the interceptor and missile is determined, relying on the solution to *Kepler's problem.* The formulation of Kepler's problem allows us to determine the orbital position of a body, given any previous position for it and the time of flight between the two positions in the orbit. Although derived by Kepler for orbiting bodies, this method can be used to model and simulate missile flights, because missiles do follow an orbital trajectory in their post-boost phase.

The most popular mechanism of mathematically representing the laws in the Lambert and Kepler problems and numerically solving them is the *universal formulation method*.[56] This method allows multiple propagations from an originating location and epoch, using the same function across the various types of conics. For cases in which thrusting and maneuvering are not important, this is a faster alternative to other methods.[57] The computing software Matlab was used to program these algorithms for simulating the various intercepts studied in this report.

The methodology employed to perform the calculations discussed in this report assumes impulsive interceptors and missiles that spontaneously obtain their entire velocity immediately upon launch. This assumption is made to simplify the mathematical complexity. Similarly, the calculations were done assuming no air drag and a nonrotating Earth. The modeling of the interception was done assuming perfect tracking information and no countermeasures from the target missile. The end game of the interception process was also not modeled. Given the ranges and times involved in comparing the kinematic reach of different interceptors, these assumptions and simplifications are reasonable for a first-order estimation.

EPAA Against Present Iranian Threats

Current Iranian missile threats to U.S. bases and assets emerge primarily from Shahab-3 missiles. The two-stage, solid-propellant Sajjil or Ashura missile with a range of 2,000 km is also a current threat. However, because Iran possesses more Shahab-3 missiles in its inventory, the following discussion will focus on that threat. The Shahab-3 and its variants are single-stage, liquid-fuel propellant missiles with a range from 1,500 km to 2,500 km. This section of the report focuses on a few potential U.S. bases that Iran could target using its Shahab-3 missiles and the ability of the EPAA interceptors to kinematically reach these missile threats.

For this research, Iranian missiles targeting two U.S. bases in Turkey were considered. First was the Incirlik Air Base in Turkey, at a distance of 964 km from the Iranian missile launch site at Tabriz. Both a minimum energy missile trajectory (Case I, Figure 3.1) and a depressed missile trajectory (Case II, Figure 3.2) for the Iranian missiles were considered. The EPAA SM-3 IB interceptors (3.5 km/s burnout velocity) located in the Eastern Mediterranean Sea were able to reach this Iranian missile, with a time delay of 100 seconds for both the minimum energy trajectory case and the depressed trajectory case. Time delays account for the time needed for the early-warning satellites and missile tracking radars to track the target missile and pinpoint a location in space for intercept. In the case of the Shahab-3 missiles, 100 seconds gives enough time to observe the entire boost phase missile (90 seconds), plus some more time to calculate the

[56] David A. Vallado, "Fundamentals of Astrodynamics and Applications," New York: McGraw-Hill Companies, 1997; and Roger R. Bate, Donald D. Mueller, and Jerry E. White, "Fundamentals of Astrodynamics," Dover Publications, Inc., New York, 1971.

[57] The algorithm for the universal formulation of Lambert and the Kepler problem can be found in Vallado, 1997, pp. 262, 440.

intercept point, assuming that the early-warning satellites and radar in the region are able to track the missile.

It should be noted that the SM-3 IB interceptors (3.5 km/s burnout velocity) located in Deveselu as part of the EPAA Phase 1 Aegis Ashore site do not have the ability to kinematically engage Iranian missiles attacking the Incirlik Air Base even under an idealized condition of zero time delay (Case III, Figure 3.3).

The second site considered for this research was the Izmir Air Base in Turkey, at a distance of 1,670 km from the Iranian missile launch site at Tabriz. Again, both a minimum-energy missile trajectory and a depressed missile trajectory for the Iranian missiles were considered. The EPAA SM-3 IB interceptors with a burnout velocity of 3.5 km/s located in the Eastern Mediterranean Sea were able to reach this Iranian missile (Case IV, Figure 3.4). Given the longer distance and the consequently longer flight path of an Iranian missile flying to Izmir from Tabriz, SM-3 IB interceptors (3.5 km/s burnout velocity) located in Deveselu as part of the EPAA Phase 1 Aegis Ashore site were able to kinematically engage minimum energy trajectory (Case V, Figure 3.5) and depressed trajectory (Case VI, Figure 3.6) Iranian missiles with a time delay of 100 seconds.

The performance of the various EPAA interceptors against current Iranian missile threats is summarized in Table 3.1. The kinematic details of each engagement follow. The highlighted red zone in the table indicates that SM-3 interceptors at Deveselu are not able to engage Iranian missiles targeting Incirlik Air Base in Turkey. However, SM-3 interceptors deployed on Aegis ships located in the Eastern Mediterranean Sea will be able to engage this particular trajectory.

Table 3.1. Performance of EPAA Interceptors Against Current Iranian Threats

Interceptor	Interceptor Location	Target Missile	Targeted Location	Distance to targeted location (km)	Intercept Possible?
SM-3 IB (V_{bo}=3.5 km/s)	Eastern Mediterranean Sea	Iranian Shahab-3/3A	Incirlik Air Base, Turkey	964	YES
SM-3 IB (V_{bo}=3.5 km/s)	Eastern Mediterranean Sea	Iranian Shahab-3/3A (depressed trajectory)	Incirlik Air Base, Turkey	964	YES
SM-3 IB (V_{bo}=3.5 km/s)	Deveselu, Romania	Iranian Shahab-3/3A	Incirlik Air Base, Turkey	964	NO
SM-3 IB (V_{bo}=3.5 km/s)	Eastern Mediterranean Sea	Iranian Shahab-3/3A	Izmir Air Base, Turkey	1670	YES
SM-3 IB (V_{bo}=3.5 km/s)	Deveselu, Romania	Iranian Shahab-3/3A	Izmir Air Base, Turkey	1670	YES
SM-3 IB (V_{bo}=3.5 km/s)	Deveselu, Romania	Iranian Shahab-3/3A (depressed trajectory)	Izmir Air Base, Turkey	1670	YES

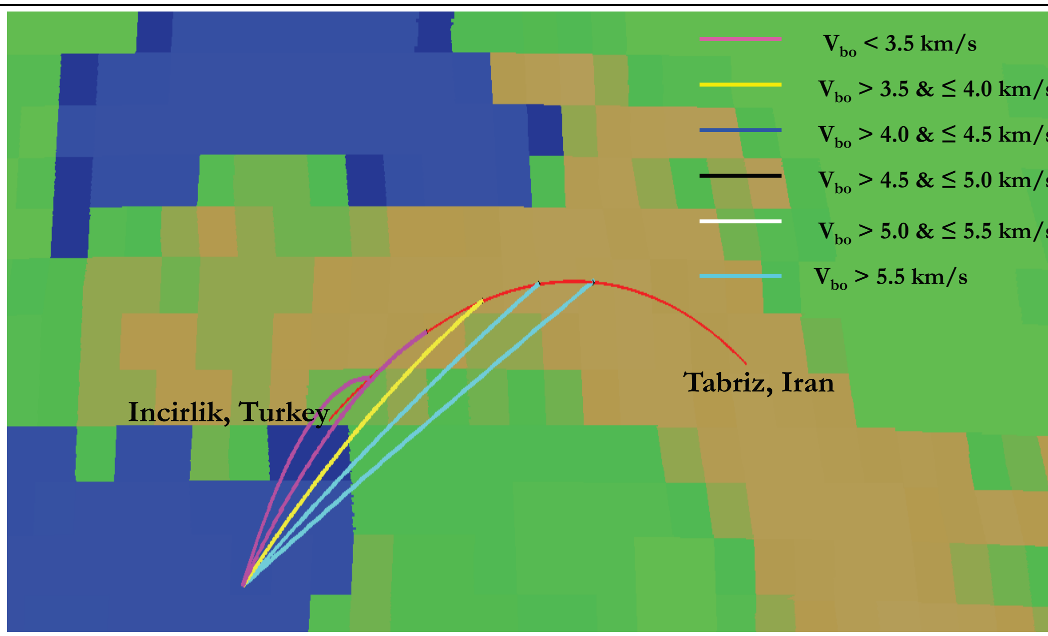
Case I: EPAA SM-3 IB Interceptors on Aegis Ships in the Eastern Mediterranean Sea Defending Against Shahab-3 Targeting Incirlik, Turkey

The EPAA SM-3 IB interceptors (3.5 km/s burnout velocity) on Aegis BMD ships located in the Eastern Mediterranean Sea will be able to kinematically reach Iranian Shahab-3 missiles targeting Incirlik Air Base in Turkey, as shown in Figure 3.1. The red trajectory indicates the target Iranian missile. The other colored trajectories show the velocities needed from an interceptor to kinematically reach the target missile after a time delay of 100 seconds. The two trajectories in pink show that it is indeed feasible for an interceptor to reach the target missile of interest with velocity less than or equal to 3.5 km/s.

Figure 3.1. Defending Against an Iranian Short-Range Attack on Incirlik Air Base, Turkey, from Aegis Ships

Offense: Iranian Shahab-3/3A missile attack from Tabriz, Iran, on Incirlik Air Base, Turkey (964 km)

Defense: From ship-based SM-3 IB (V_{bo} = 3.5 km/s) located in the Eastern Mediterranean Sea



ASSUMPTIONS: (1) Perfect tracking information, (2) minimum energy trajectory, and (3) no countermeasures

Case II: EPAA SM-3 IB Interceptors on Aegis Ships in the Eastern Mediterranean Sea Defending Against Depressed Trajectory Shahab-3 Targeting Incirlik, Turkey

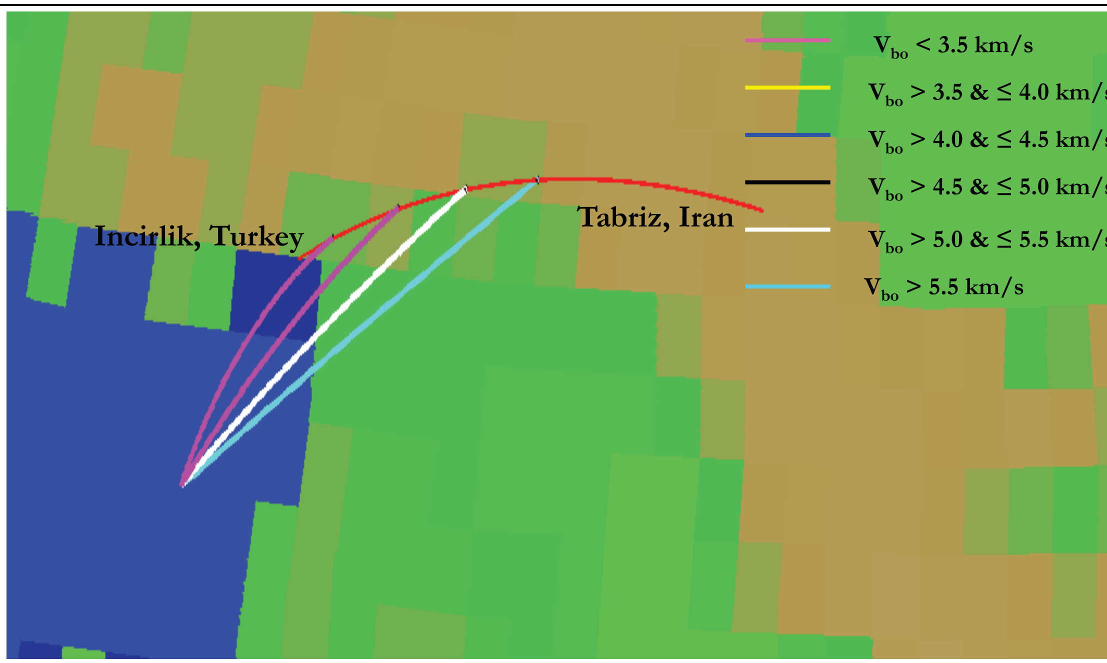
The EPAA SM-3 IB interceptors (3.5 km/s burnout velocity) on Aegis BMD ships located in the Eastern Mediterranean Sea will be able to kinematically reach depressed-trajectory (with a 15-percent shorter flight time) Iranian Shahab-3 missiles targeting Incirlik Air Base in Turkey, with a 100-second time delay, as shown in Figure 3.2. The same is true for missiles traveling on a lofted trajectory (with a 15-percent longer flight time).

Figure 3.2. Defending Against an Iranian Short-Range, Depressed-Trajectory Attack on Incirlik Air Base, Turkey, from Aegis Ships

Offense: Iranian Shahab-3/3A missile depressed-trajectory* attack from Tabriz, Iran, on Incirlik Air Base, Turkey (964 km)

Defense: From ship-based SM-3 IB (V_{bo} = 3.5 km/s) located in the Eastern Mediterranean Sea

*15% shorter time of flight



ASSUMPTIONS: (1) Perfect tracking information, (2) minimum energy trajectory, and (3) no countermeasures

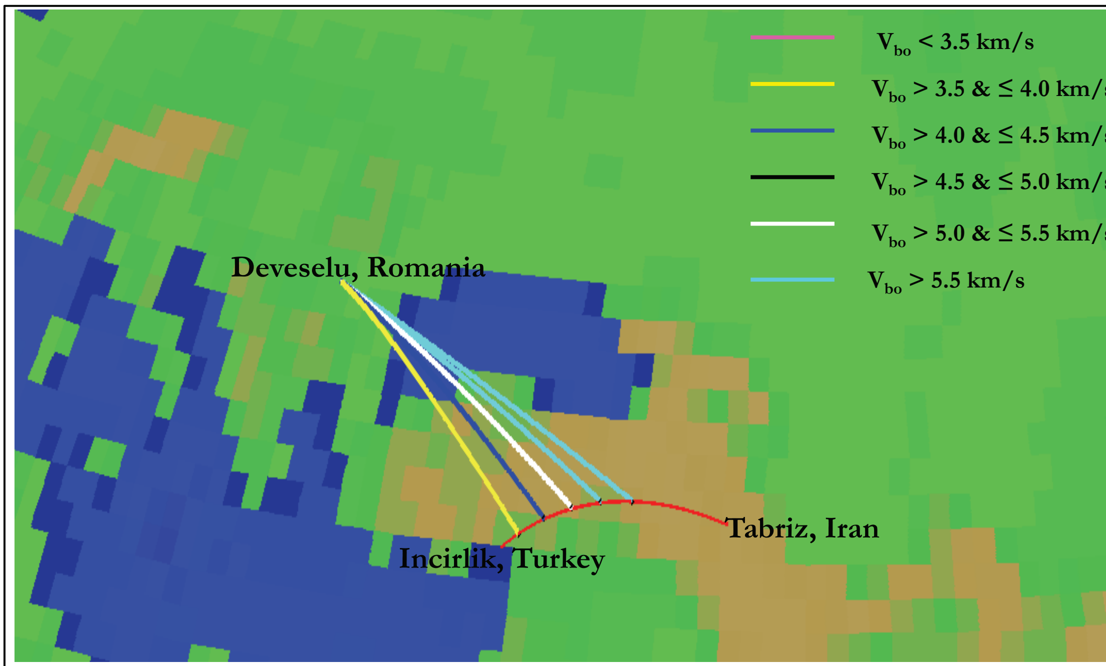
Case III: EPAA SM-3 IB Interceptors at Aegis Ashore Site in Deveselu, Romania, Defending Against Shahab-3 Targeting Incirlik, Turkey

The EPAA SM-3 IB interceptors (3.5 km/s burnout velocity) located at the Aegis Ashore site in Deveselu will not be able to kinematically reach Iranian Shahab-3 missiles targeting Incirlik Air Base in Turkey, with no time delay, as shown in Figure 3.3.

Figure 3.3. Defending Against an Iranian Short-Range Attack on Incirlik Air Base, Turkey, from Deveselu, Romania

Offense: Iranian Shahab-3/3A missile attack from Tabriz, Iran, on Incirlik Air Base, Turkey (964 km)

Defense: From Aegis Ashore SM-3 IB (V_{bo} = 3.5 km/s) located in Deveselu, Romania



ASSUMPTIONS: (1) Perfect tracking information, (2) minimum energy trajectory, and (3) no countermeasures

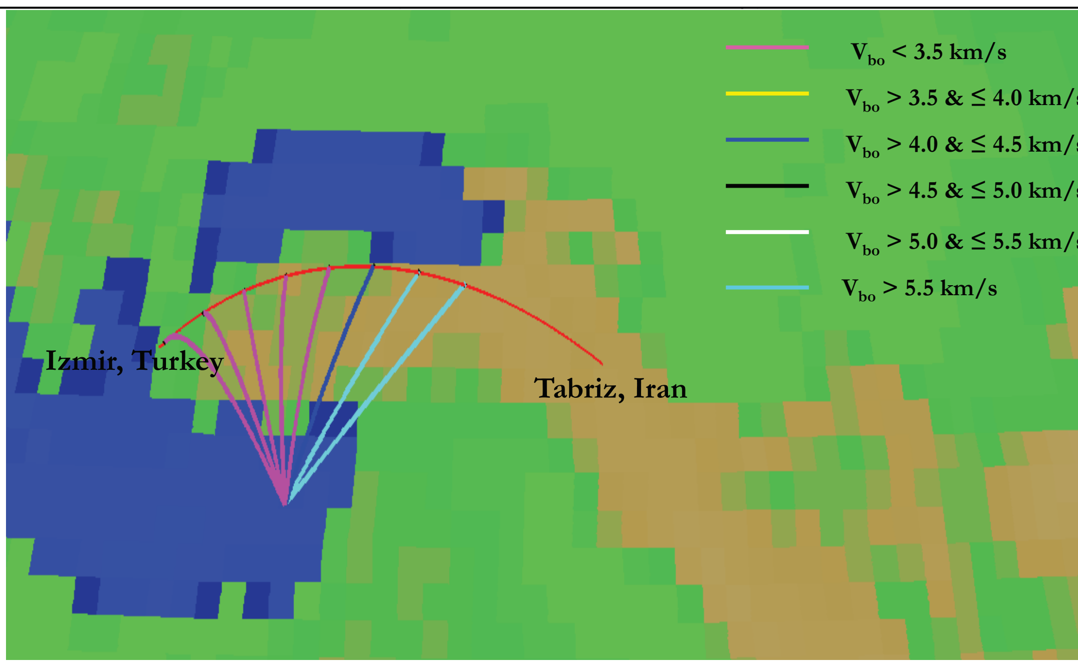
Case VI: EPAA SM-3 IB Interceptors on Aegis Ships in the Eastern Mediterranean Sea Defending Against Shahab-3 Targeting Izmir, Turkey

The EPAA SM-3 IB interceptors (3.5 km/s burnout velocity) on Aegis BMD ships located in the Eastern Mediterranean Sea will be able to kinematically reach Iranian Shahab-3 missiles targeting Izmir Air Base in Turkey, with a 100-second time delay, as shown in Figure 3.4. Also, Shahab-3 missiles traveling on a lofted trajectory (with 15-percent longer flight time) can be intercepted.

Figure 3.4. Defending Against an Iranian Medium-Range Attack on Izmir Air Base, Turkey, from the Mediterranean Sea

Offense: Iranian Shahab-3/3A missile attack from Tabriz, Iran, on Izmir Air Base, Turkey (1,670 km)

Defense: From ship-based SM-3 IB (V_{bo} = 3.5 km/s) located in the Eastern Mediterranean Sea



ASSUMPTIONS: (1) Perfect tracking information, (2) minimum energy trajectory, and (3) no countermeasures

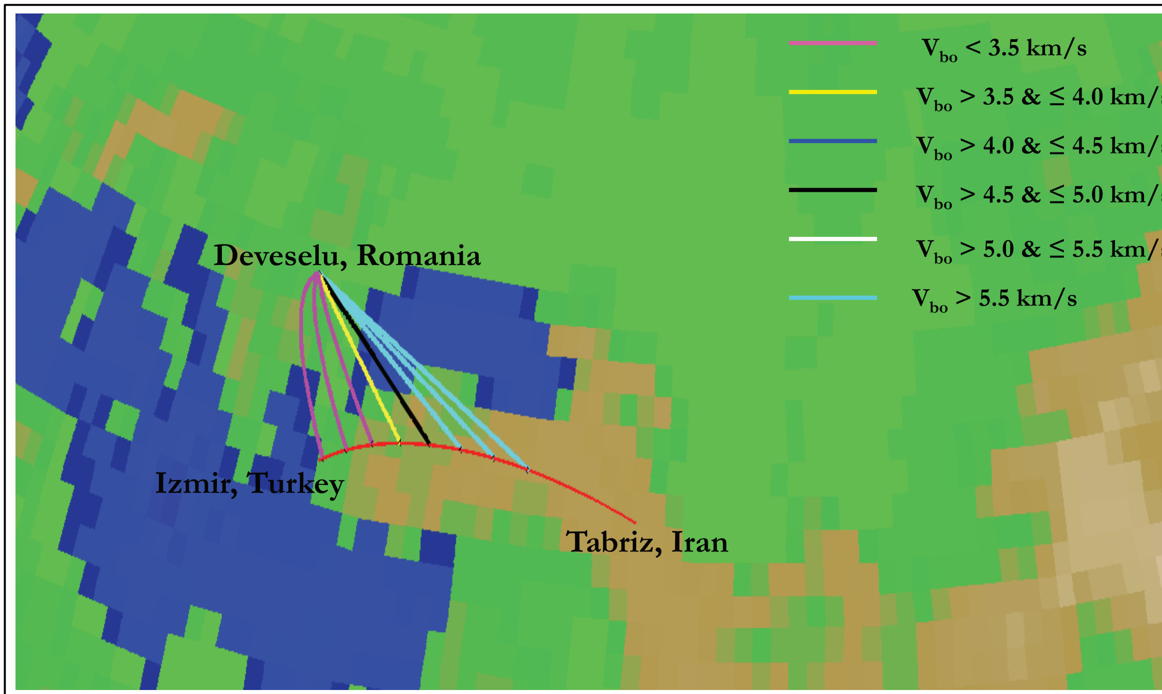
Case V: EPAA SM-3 IB Interceptors at Aegis Ashore Site in Deveselu, Romania, Defending Against Shahab-3 Targeting Izmir, Turkey

The EPAA SM-3 IB interceptors (3.5 km/s burnout velocity) located at the Aegis Ashore site in Deveselu will be able to kinematically reach Iranian Shahab-3 missiles targeting Izmir Air Base in Turkey, with a 100-second time delay, as shown in Figure 3.5.

Figure 3.5. Defending Against an Iranian Medium-Range Attack on Izmir Air Base, Turkey, from Deveselu, Romania

Offense: Iranian Shahab-3/3A missile attack from Tabriz, Iran, on Izmir Air Base, Turkey (1,670 km)

Defense: From Aegis Ashore SM-3 IB (V_{bo} = 3.5 km/s) located in Deveselu, Romania



ASSUMPTIONS: (1) Perfect tracking information, (2) minimum energy trajectory, and (3) No countermeasures

Case VI: EPAA SM-3 IB Interceptors at Aegis Ashore Site in Deveselu, Romania, Defending Against Depressed Trajectory Shahab-3 Targeting Izmir, Turkey

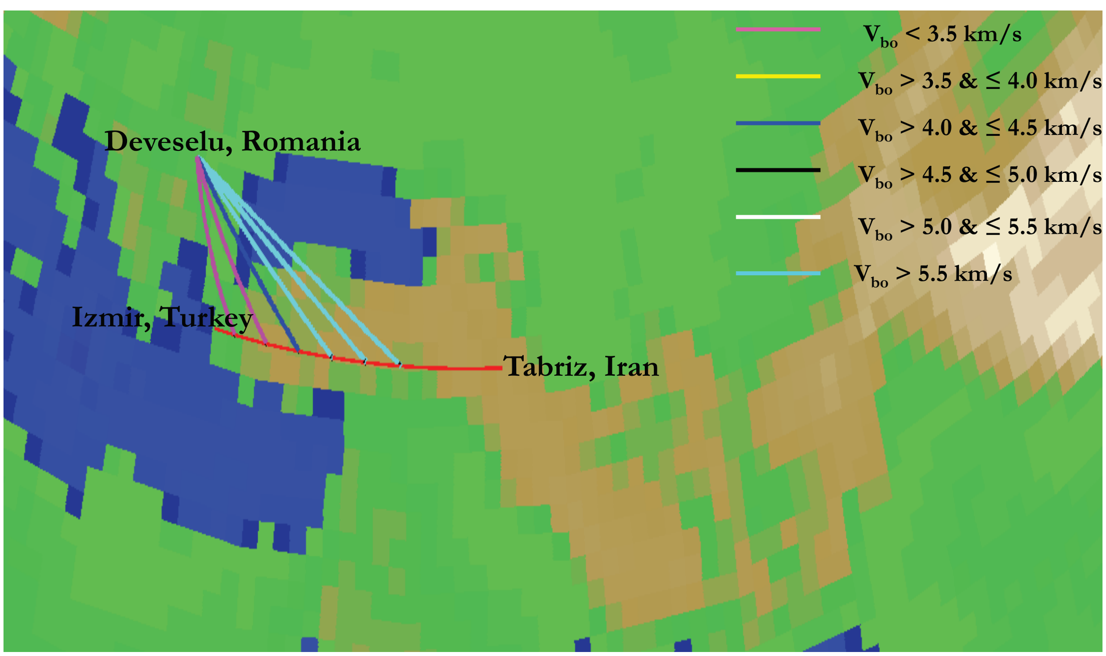
The EPAA SM-3 IB interceptors (3.5 km/s burnout velocity) located at Aegis Ashore site in Deveselu will be able to kinematically reach depressed-trajectory (with a 15-percent shorter flight time) Iranian Shahab-3 missiles targeting Izmir Air Base in Turkey, with a 100-second time delay, as shown in Figure 3.6. The same is also true for missiles traveling on a lofted trajectory (with a 15-percent longer flight time).

Figure 3.6. Defending Against an Iranian Medium-Range, Depressed-Trajectory Attack on Izmir Air Base, Turkey, from Deveselu, Romania

Offense: Iranian Shahab-3/3A missile depressed-trajectory* attack from Tabriz, Iran, on Izmir Air Base, Turkey (1,670 km)

Defense: From Aegis Ashore SM-3 IB (V_{bo} = 3.5 km/s) located in Deveselu, Romania

*15% shorter time of flight



ASSUMPTIONS: (1) Perfect tracking information, (2) minimum energy trajectory, and (3) no countermeasures

EPAA Against Future Iranian Threats

The most plausible future missile threat from Iran that could threaten U.S. bases deeper in Europe is the two-stage, liquid-propellant Safir IRBM with a maximum range of 5,200 km. This section of the report focuses on a few potential U.S. bases that Iran could target using its Safir missiles and analyzes the ability of the EPAA interceptors to kinematically reach these missile threats from Iran. By demonstrating that the restructured EPAA system can fulfill its mission without the now-canceled advanced SM-3 IIB interceptors, this section shows that the EPAA system is still as effective against Iran.

Under consideration were Iranian Safir missiles targeting four U.S. bases or major cities in Italy, Germany, the United Kingdom, and Spain.[58] First, an Iranian Safir missile targeting the U.S. base Camp Darby in Italy, at a distance of 3,064 km from the Iranian missile launch site at Tabriz, was considered. The EPAA Phase 2 SM-3 IB interceptors (3.5 km/s burnout velocity) located in Deveselu are able to reach this Iranian missile with a time delay of 190 seconds (Case VII, Figure 3.7). EPAA Phase 3 SM-3 IIA interceptors (4.5 km/s burnout velocity) located in Redzikowo are also able to reach this Iranian missile (Case VIII, Figure 3.8). Second, an Iranian Safir missile targeting the Ramstein Air Base in Germany, at a distance of 3,309 km from the Iranian missile launch site at Tabriz, was considered. Both the EPAA Phase 2 SM-3 IB and Phase 3 SM-3 IIA interceptors are able to reach this Iranian missile (Case IX, Figure 3.9, and Case X, Figure 3.10, respectively).

Third, an Iranian Safir missile targeting London, United Kingdom, at a distance of 3,876 km from the Iranian missile launch site at Tabriz, was considered. The EPAA Phase 2 SM-3 IB interceptors (3.5 km/s burnout velocity) located in Deveselu will not be able to reach this Iranian missile with a time delay of 190 seconds (Case XI, Figure 3.11). EPAA Phase 3 SM-3 IIA interceptors (4.5 km/s burnout velocity) located in Redzikowo are needed to intercept Iranian IRBMs heading to London (Case XII, Figure 3.12). Finally, an Iranian Safir missile targeting the U.S. naval base in Rota, Spain, at a distance of 4,529 km from the Iranian missile launch site at Tabriz, was considered. Neither the EPAA Phase 2 SM-3 IB interceptors (3.5 km/s burnout velocity) located in Deveselu (Case XIII, Figure 3.13) nor the EPAA Phase 3 SM-3 IIA interceptors (4.5 km/s burnout velocity) located in Redzikowo will be able to intercept this Iranian IRBM (Case XIV, Figure 3.14). However, Aegis BMD ships with SM-3 IB interceptors located in the Western Mediterranean Sea will be able to intercept the missile (Case XV, Figure 3.15).

The performance of the various EPAA interceptors against these future Iranian missile threats is summarized in Table 2.2. The details of each engagement follow. The highlighted red

[58] This calculation is done with the assumption of a nonrotating Earth still in place. For westerly trajectories, the rotation of the Earth might make it comparatively more demanding for the Iranian Safir missile to reach such locations as Rota, Spain. The effect of relaxing the assumption and testing the sensitivity of the results discussed will be done in future iterations of this work.

zone in the table indicates that SM-3 interceptors at Deveselu are not able to engage an Iranian missile targeting London. However, SM-3 interceptors deployed at Redzikowo will be able to engage this particular trajectory.

Table 3.2. Performance of EPAA Interceptors Against Future Iranian Threats

Interceptor	Interceptor Location	Target Missile	Targeted Location	Distance to targeted location (km)	Intercept Possible?
SM-3 IB (V_{bo}=3.5 km/s)	Deveselu, Romania	Iranian Safir	Camp Darby, Italy	3064	YES
SM-3 IIA (V_{bo}=4.5 km/s)	Redzikowo, Poland	Iranian Safir	Camp Darby, Italy	3064	YES
SM-3 IB (V_{bo}=3.5 km/s)	Deveselu, Romania	Iranian Safir	Ramstein Air Base, Germany	3309	YES
SM-3 IIA (V_{bo}=4.5 km/s)	Redzikowo, Poland	Iranian Safir	Ramstein Air Base, Germany	3309	YES
SM-3 IB (V_{bo}=3.5 km/s)	Deveselu, Romania	Iranian Safir	London, U.K.	3876	NO
SM-3 IIA (V_{bo}=4.5 km/s)	Redzikowo, Poland	Iranian Safir	London, U.K.	3876	YES
SM-3 IB (V_{bo}=3.5 km/s)	Western Mediterranean Sea	Iranian Safir	Rota, Spain	4529	YES

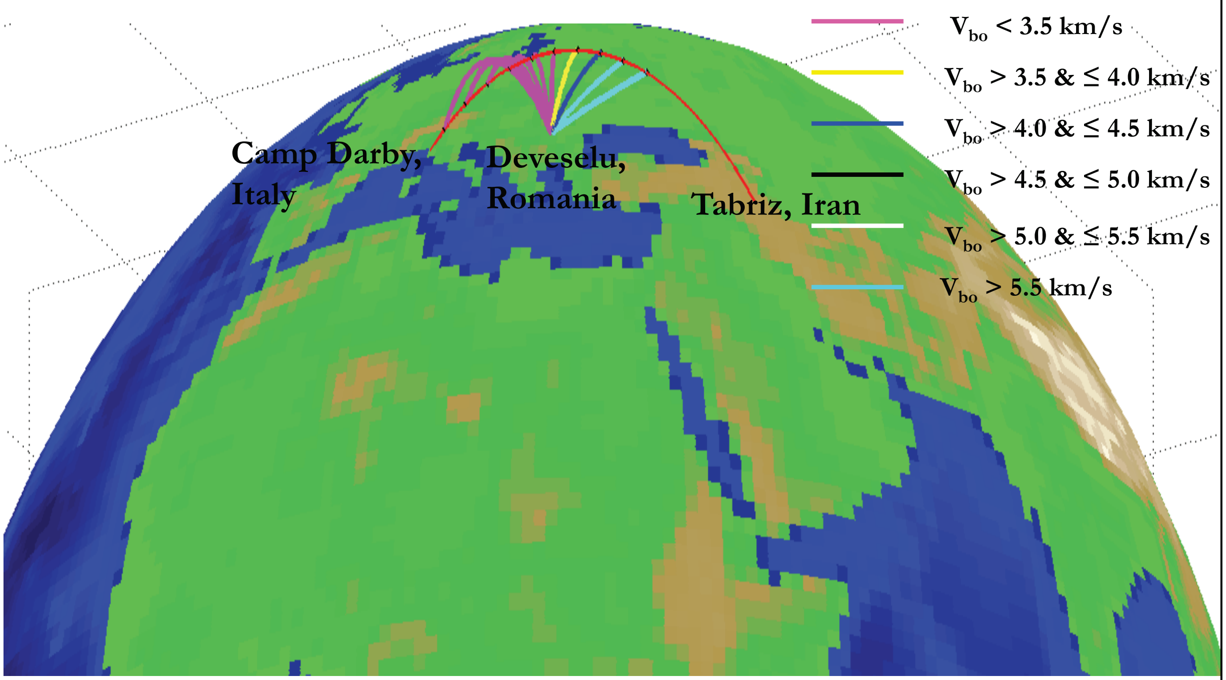
Case VII: EPAA SM-3 IB Interceptors at Aegis Ashore Site in Deveselu, Romania, Defending Against Safir Missile Targeting Camp Darby, Italy

The EPAA SM-3 IB interceptors located at the Aegis Ashore site in Deveselu will be able to kinematically reach Iranian Safir missiles targeting Camp Darby in Italy, with a 190-second time delay, as shown in Figure 3.7.

Figure 3.7. Defending Against an Iranian Medium-Range Attack on Camp Darby, Italy, from Deveselu, Romania

Offense: Iranian Safir missile attack from Tabriz, Iran, on Camp Darby, Italy (3,064 km)

Defense: From Aegis Ashore SM-3 IB (V_{bo} = 3.5 km/s) located in Deveselu, Romania



ASSUMPTIONS: (1) Perfect tracking information, (2) minimum energy trajectory, and (3) no countermeasures

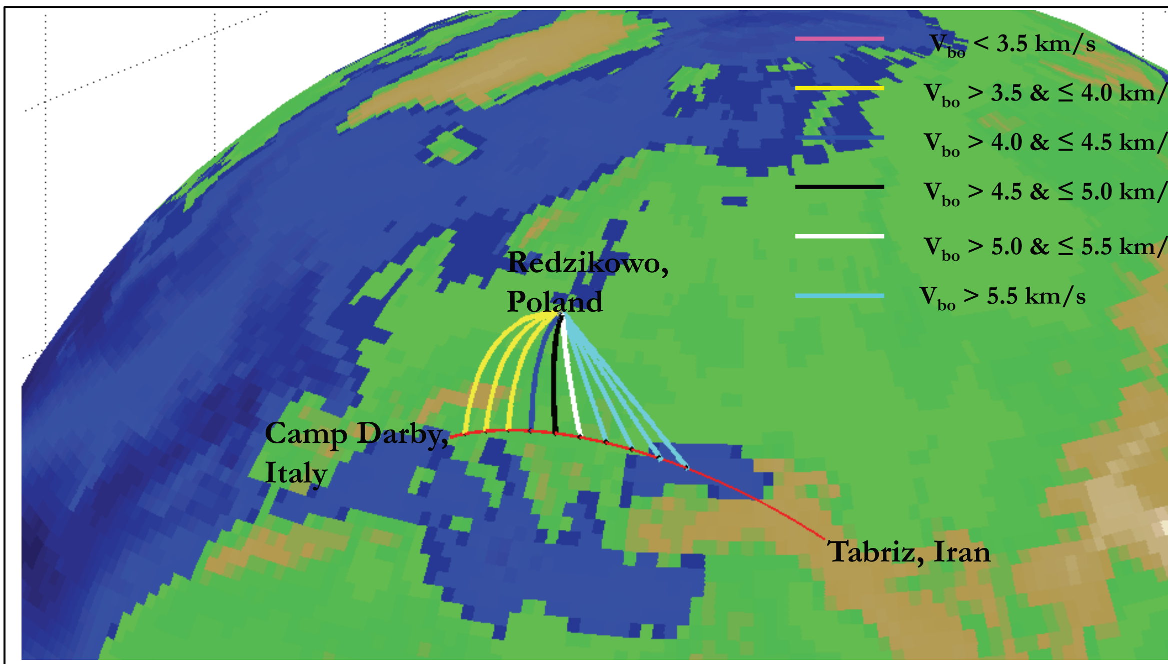
Case VIII: EPAA SM-3 IIA Interceptors at Aegis Ashore Site in Redzikowo, Poland, Defending Against Safir Missile Targeting Camp Darby, Italy

The EPAA SM-3 IIA interceptors located at the Aegis Ashore site in Redzikowo will be able to kinematically reach Iranian Safir missiles targeting Camp Darby in Italy, with a 190-second time delay, as shown in Figure 3.8.

Figure 3.8. Defending Against an Iranian Medium-Range Attack on Camp Darby, Italy, from Redzikowo, Poland

Offense: Iranian Safir missile attack from Tabriz, Iran, on Camp Darby, Italy (3,064 km)

Defense: From Aegis Ashore SM-3 IIA (V_{bo} = 4.5 km/s) located in Redzikowo, Poland



ASSUMPTIONS: (1) Perfect tracking information, (2) minimum energy trajectory, and (3) no countermeasures

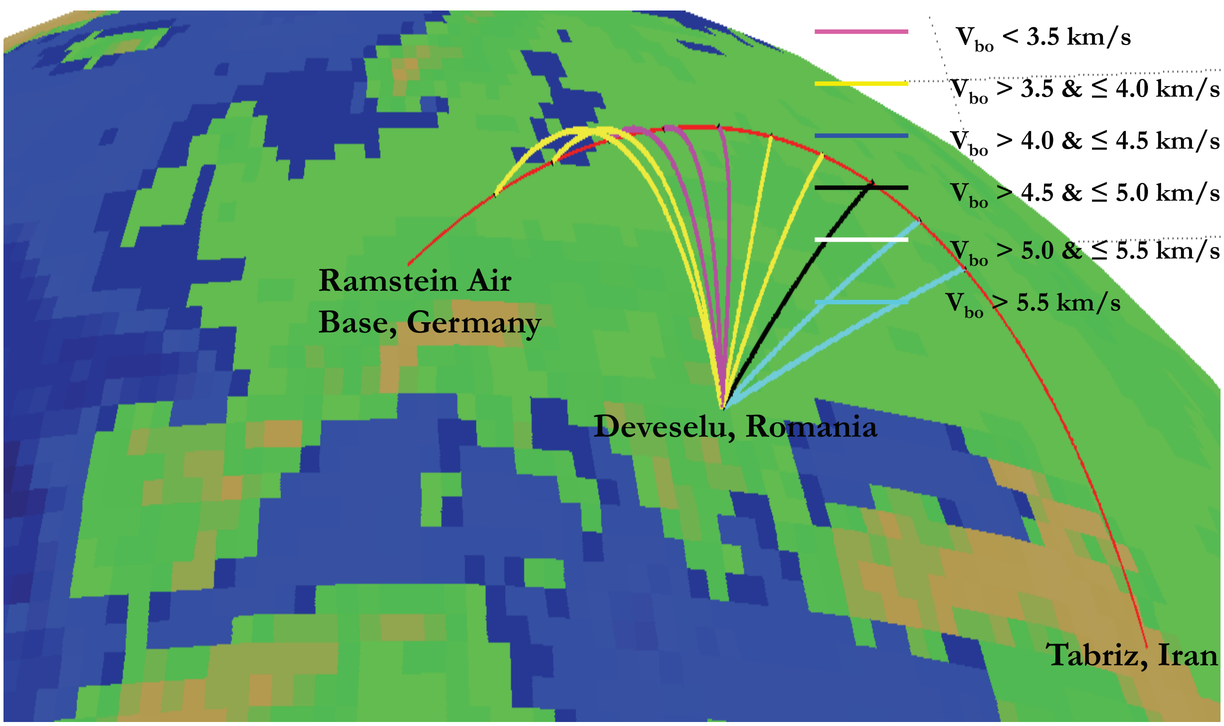
Case IX: EPAA SM-3 IB Interceptors at Aegis Ashore Site in Deveselu, Romania, Defending Against Safir Missile Targeting Ramstein Air Base, Germany

The EPAA SM-3 IB interceptors located at the Aegis Ashore site in Deveselu will be able to kinematically reach Iranian Safir missiles targeting Ramstein Air Base in Germany, with a 190-second time delay, as shown in Figure 3.9.

Figure 3.9. Defending Against an Iranian Intermediate-Range Attack on Ramstein Air Base, Germany, from Deveselu, Romania

Offense: Iranian Safir missile attack from Tabriz, Iran, on Ramstein Air Base, Germany (3,309 km)

Defense: From Aegis Ashore SM-3 IB (V_{bo} = 3.5 km/s) located in Deveselu, Romania



ASSUMPTIONS: (1) Perfect tracking information, (2) minimum energy trajectory, and (3) no countermeasures

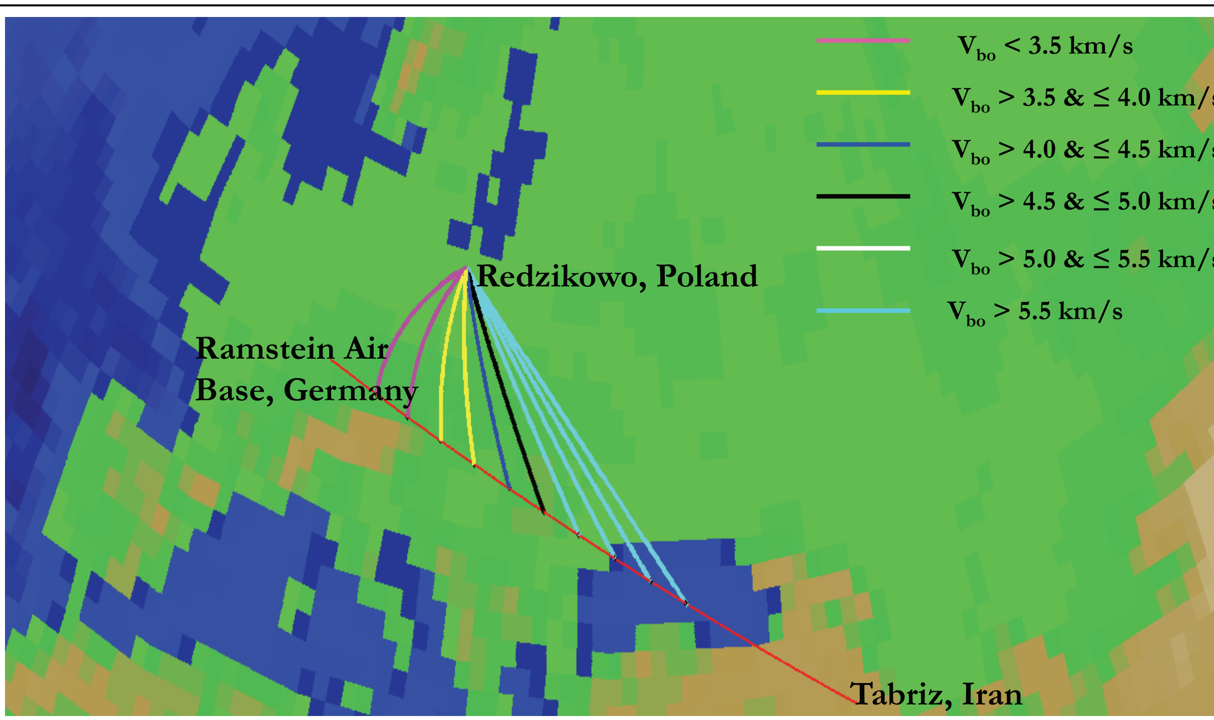
Case X: EPAA SM-3 IIA Interceptors at Aegis Ashore Site in Redzikowo, Poland, Defending Against Safir Missile Targeting Ramstein Air Base, Germany

The EPAA SM-3 IIA interceptors located at the Aegis Ashore site in Redzikowo will be able to kinematically reach Iranian Safir missiles targeting Ramstein Air Base in Germany, with a 190-second time delay, as shown in Figure 3.10.

Figure 3.10. Defending Against an Iranian Intermediate-Range Attack on Ramstein Air Base, Germany, from Redzikowo, Poland

Offense: Iranian Safir missile attack from Tabriz, Iran, on Ramstein Air Base, Germany (3,309 km)

Defense: From Aegis Ashore SM-3 IIA (V_{bo} = 4.5 km/s) located in Redzikowo, Poland



ASSUMPTIONS: (1) Perfect tracking information, (2) minimum energy trajectory, and (3) no countermeasures

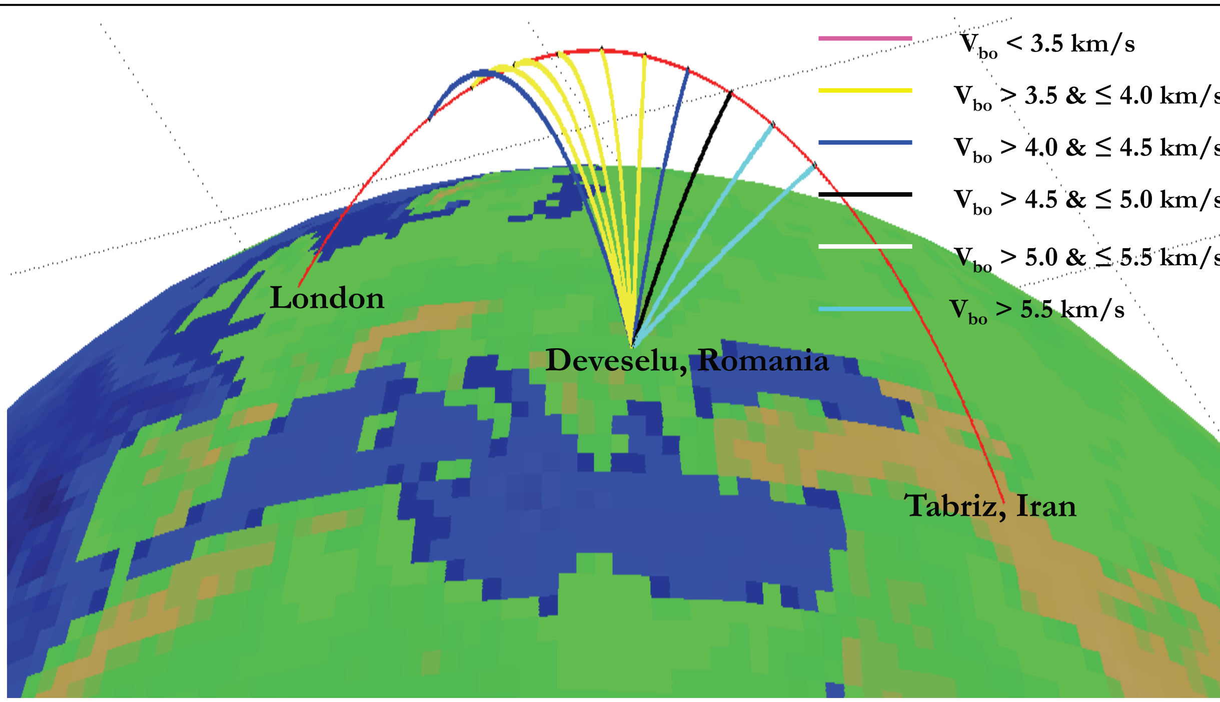
Case XI: EPAA SM-3 IB Interceptors at Aegis Ashore Site in Deveselu, Romania, Defending Against Safir Missile Targeting London

The EPAA SM-3 IB interceptors located at the Aegis Ashore site in Deveselu will not be able to kinematically reach Iranian Safir missiles targeting London, with a 190-second time delay, as shown in Figure 3.11.

Figure 3.11. Defending Against an Iranian Intermediate-Range Attack on London from Deveselu, Romania

Offense: Iranian Safir missile attack from Tabriz, Iran, on London (3,876 km)

Defense: From Aegis Ashore SM-3 IB (V_{bo} = 3.5 km/s) located in Deveselu, Romania



ASSUMPTIONS: (1) Perfect tracking information, (2) minimum energy trajectory, and (3) no countermeasures

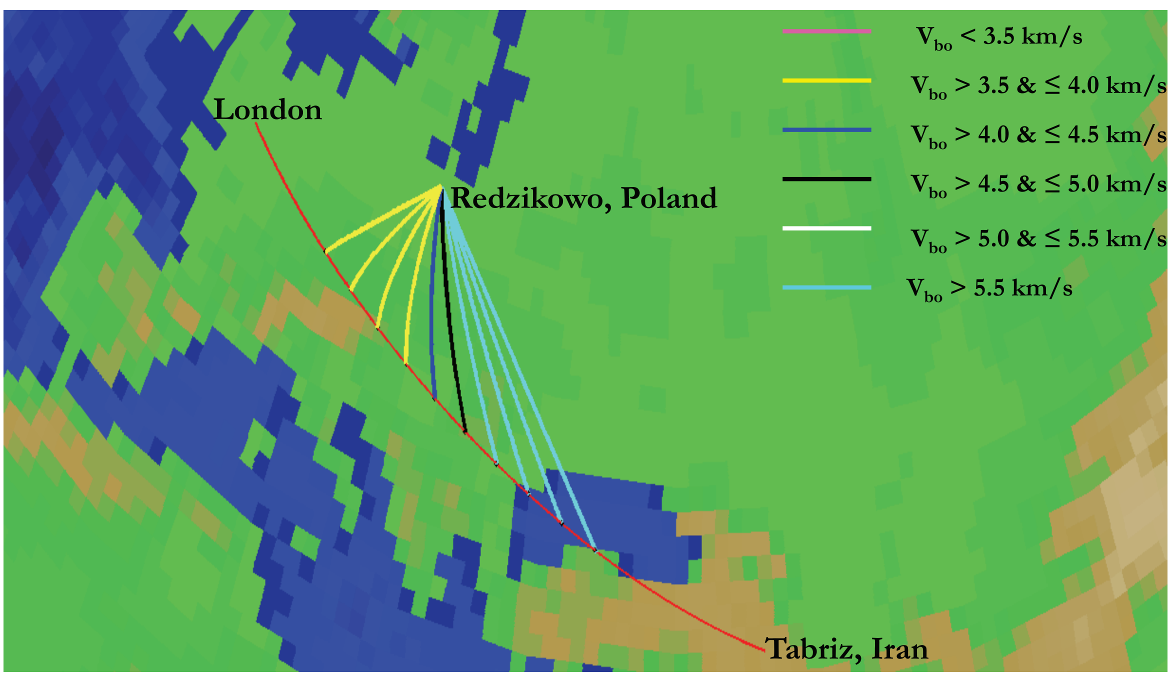
Case XII: EPAA SM-3 IIA Interceptors at Aegis Ashore Site in Redzikowo, Poland, Defending Against Safir Missile Targeting London

The EPAA SM-3 IIA interceptors located at the Aegis Ashore site in Redzikowo will be able to kinematically reach Iranian Safir missiles targeting London, with a 190-second time delay, as shown in Figure 3.12. The same target trajectory when launched in a lofted fashion (therefore taking 15 percent more travel time) is still subject to interception, provided that the sensors are able to find and track it.

Figure 3.12. Defending Against an Iranian Intermediate-Range Attack on London from Redzikowo, Poland

Offense: Iranian Safir missile attack from Tabriz, Iran, on London (3,876 km)

Defense: From Aegis Ashore SM-3 IIA (V_{bo} = 4.5 km/s) located in Redzikowo, Poland



ASSUMPTIONS: (1) Perfect tracking information, (2) minimum energy trajectory, and (3) no countermeasures

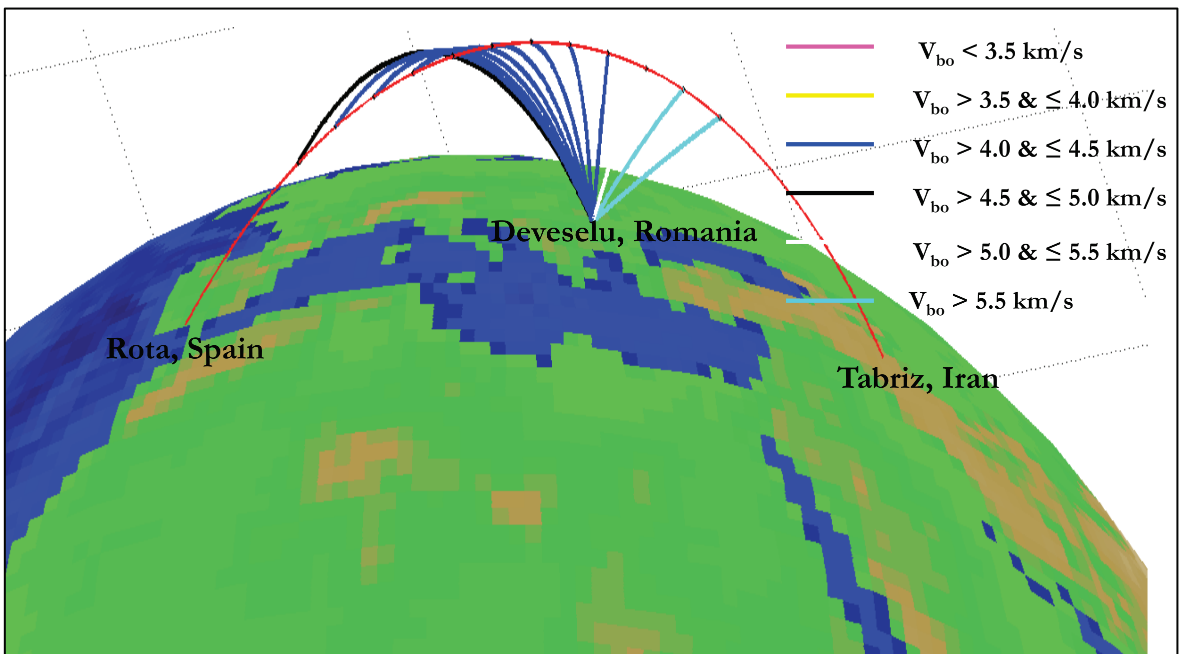
Case XIII: EPAA SM-3 IB Interceptors at Aegis Ashore Site in Deveselu, Romania, Defending Against Safir Missile Targeting Rota, Spain

The EPAA SM-3 IB interceptors located at the Aegis Ashore site in Deveselu will not be able to kinematically reach Iranian Safir missiles targeting the U.S. naval base in Rota, Spain, with a 190-second time delay, as shown in Figure 3.13. However, an EPAA SM3-IIA (4.5 km/s burnout velocity) launched from Deveselu will be able to intercept Safir missiles traveling to Rota from Tabriz.

Figure 3.13. Defending Against an Iranian Intermediate-Range Attack on Rota, Spain, from Deveselu, Romania

Offense: Iranian Safir missile attack from Tabriz, Iran, on Rota, Spain (4,529 km)

Defense: From Aegis Ashore SM-3 IB (V_{bo} = 3.5 km/s) located in Deveselu, Romania



ASSUMPTIONS: (1) Perfect tracking information, (2) minimum energy trajectory, and (3) no countermeasures

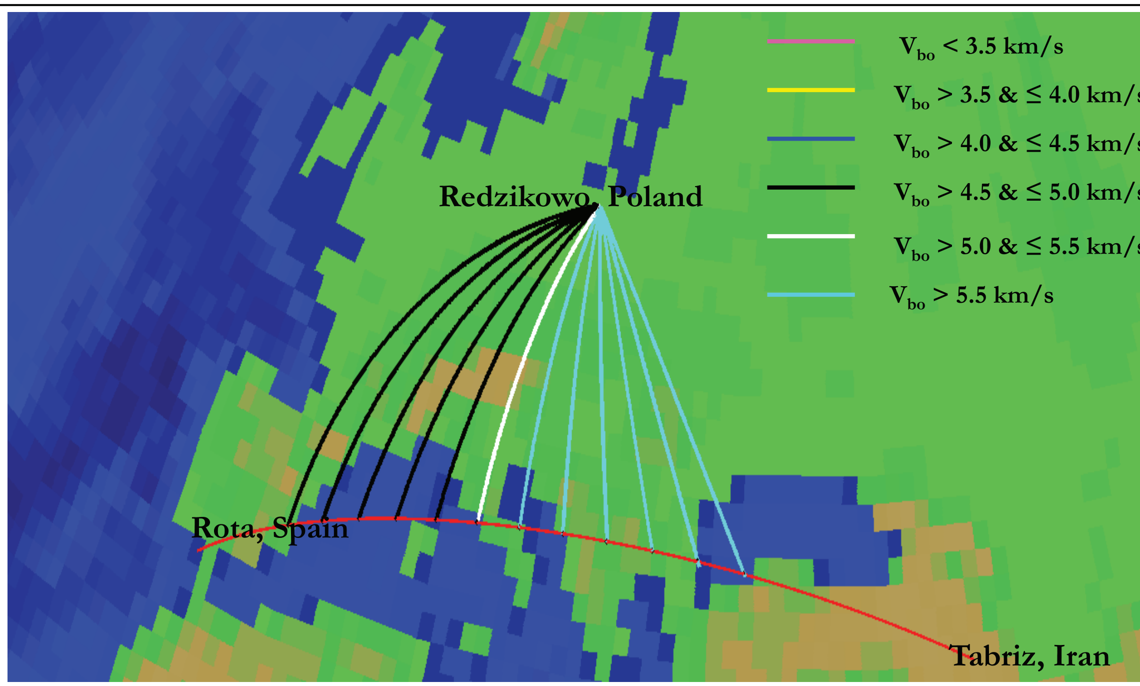
Case XIV: EPAA SM-3 IIA Interceptors at Aegis Ashore Site in Redzikowo, Poland, Defending Against Safir Missile Targeting Rota, Spain

The EPAA SM-3 IIA interceptors located at the Aegis Ashore site in Redzikowo will not be able to kinematically reach Iranian Safir missiles targeting the U.S. naval base in Rota, Spain, with a 190-second time delay, as shown in Figure 3.14.

Figure 3.14. Defending Against an Iranian Intermediate-Range Attack on Rota, Spain, from Redzikowo, Poland

Offense: Iranian Safir missile attack from Tabriz, Iran, on Rota, Spain (4,529 km)

Defense: From Aegis Ashore SM-3 IIA (V_{bo} = 4.5 km/s) located in Redzikowo, Poland



ASSUMPTIONS: (1) Perfect tracking information, (2) minimum energy trajectory, and (3) no countermeasures

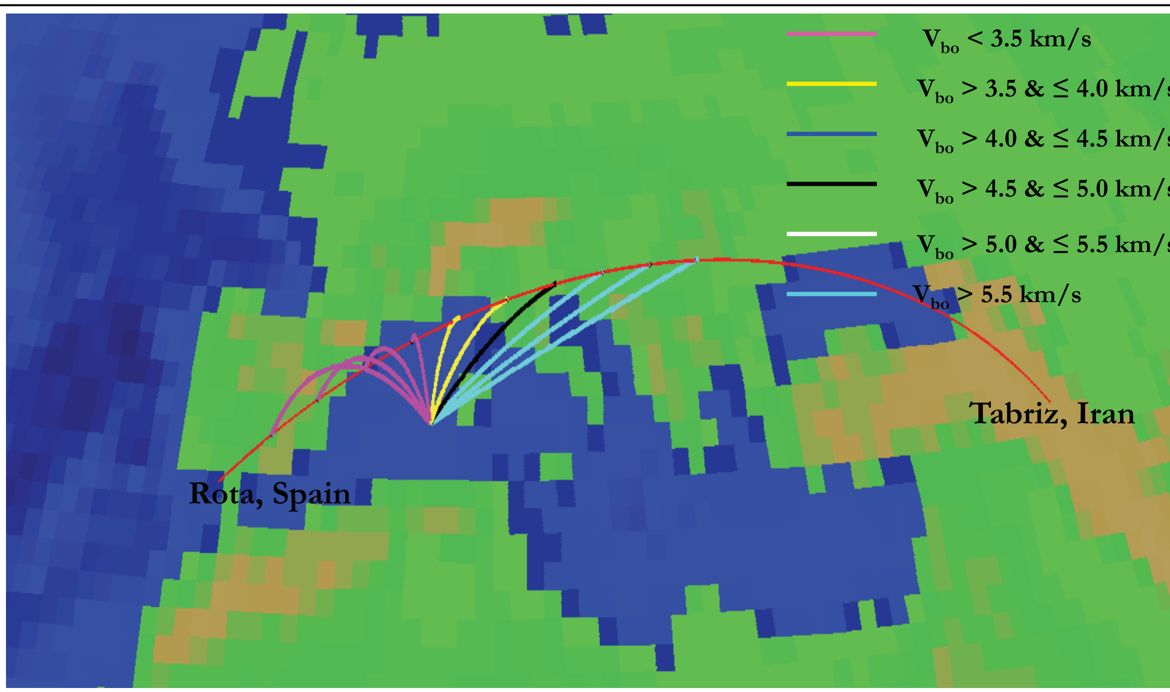
Case XV: EPAA SM-3 IB Interceptors on Aegis BMD Ships in Western Mediterranean Sea Defending Against Safir Missile Targeting Rota, Spain

Alternatively, the EPAA SM-3 IB interceptors on Aegis BMD ships located in the Western Mediterranean Sea will be able to kinematically reach Iranian Safir missiles targeting the U.S. naval base in Rota, Spain, with more than a 190-second time delay, as shown in Figure 3.15. However, because the interceptors of Aegis ships are located much farther from the launch site, they must wait longer before they can be launched.

Figure 3.15. Defending Against an Iranian Intermediate-Range Attack on Rota, Spain, from Aegis Ships in the Western Mediterranean Sea

Offense: Iranian Safir missile attack from Tabriz, Iran, on Rota, Spain (4,529 km)

Defense: From ship-based SM-3 IB (V_{bo} = 3.5 km/s) located in the Western Mediterranean Sea



ASSUMPTIONS: (1) Perfect tracking information, (2) minimum energy trajectory, and (3) no countermeasures

Summary: EPAA Against Future Iranian Threats

In summary, within the limits imposed by the assumptions made, the restructured EPAA missile defense system will be able to handle both current and future Iranian missiles under different conditions of plausible time delays (see Table 3.3). All time-delay values reflect the known burnout times of Iranian missiles, as indicated in Table 2.1 in Chapter Two. The burnout velocities needed from EPAA interceptors to handle these Iranian threats are less than 4.5 km/s, which is the maximum velocity attained by the restructured EPAA SM-3 IIA interceptors. Again, the now-canceled faster SM-3 II B interceptor, with a burnout velocity of 5.5 km/s, is not needed to address present or future Iranian threats.

Table 3.3. Performance of EPAA Interceptors Against Current and Future Iranian Missile Threats from Tabriz

Target Location	Minimum V_{bo} Required (km/s)	EPAA Location (Time Delay)
Incirlik Air Base (Shahab 3/3A)	2.24	Aegis (100 sec)
Izmir Air Base (Shahab 3/3A)	2.73	Aegis (100 sec)
Camp Darby, Italy (Safir)	3.20	Deveselu (190 sec)
Ramstein Air Base, Germany (Safir)	3.39	Redzikowo (190 sec)
London (Safir)	3.66	Redzikowo (190 sec)
Rota, Spain (Safir)	3.38	Aegis (>190 sec)

4. The Performance of EPAA Against Russian ICBMs

The primary Russian complaint about the EPAA missile defense system has been the Phase 4 advanced SM-3 IIB interceptors with a burnout velocity of 5.5 km/s that were to be deployed in Redzikowo. Some Russian experts have also brought up the possibility that Aegis BMD ships relocated to the North Sea or the Barents Sea would be better able to intercept Russian ICBMs.[59]

This chapter will examine how the cancellation of the Phase 4 interceptors has changed the alleged threat to Russia. First, the figures in this chapter will demonstrate that the interceptors in Deveselu will not be able to kinematically reach Russian ICBMs (Case XVI, Figure 4.1). Second, the analysis will show that the interceptors in Redzikowo also do not possess any capability against Russian ICBMs (Case XVII, Figure 4.2). Even under an unrealistic and ideal condition of zero time delay—that is, immediately after the launch of the target ICBM—the most powerful interceptor deployed at Redzikowo under the restructured EPAA plan, the SM-3 IIA (4.5 km/s burnout velocity), will be able to intercept ICBMs from only two Russian sites, Kozelsk and Tatishchevo, heading toward Washington, D.C. However, if the ICBMs from either Kozelsk or Tatishchevo were heading to San Francisco on the West Coast of the United States, then the SM-3 IIA (4.5 km/s burnout velocity) interceptors have no potential to intercept. In fact, even under the original conception of the phased adaptive approach and even in an idealized launch condition of zero time delay, the SM-3 IIB would be able to intercept only Russian ICBMs heading to Washington, D.C., from five of the westernmost missile sites. Modeling demonstrates that, under these conditions, Russia would still be able to launch its ICBMs at the United States from at least nine other launch sites without being intercepted.[60]

Aegis ships located in the North Sea and the Barents Sea equipped with SM-3 IIA missiles will be able to intercept Russian ICBMs only under an unrealistic zero time delay (Case XVIII, Figure 4.3 and Case XIX, Figure 4.4). Even given the unrealistic time delay, Aegis ships will have to be placed in both the North Sea and the Barents Sea to cover all possible Russian ICBM trajectories.

In reality, however, interceptors can never be launched without some delay. It takes nearly 30 seconds for the ICBM to rise above the possible cloud cover and for early-warning missile tracking satellites to recognize the launch of the ICBM.[61] After that, depending on the location of

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[59] For details, see Aleksandr Khramchikhin, "Russia: Khramchikhin Answers Criticism of His Earlier Article on Missile Defense," World News Connection, NTIS, original Russian Publication in *Nezavisimoye Voyennoye Obozreniye*, July 22, 2011.

[60] Jaganath Sankaran, "Missile Defense Against Iran Without Threatening Russia," *Arms Control Today*, November 2013.

[61] David K. Barton, Roger Falcone, Daniel Kleppner, Frederick K. Lamb, Ming K. Lau, Harvey L. Lynch, David Moncton, David Montague, David E. Mosher, William Priedhorsky, Maury Tigner, and David R. Vaughan, "Report

tracking radars, it can take as long as a couple of minutes for the system to calculate the point at which it will intercept the target missile. It seems that the closest radar that can track Russian ICBMs is the upgraded early-warning radar located at the Royal Air Force Fylingdales station in England. This radar would start tracking Russian ICBMs just as their powered flight ends, approximately three minutes after being launched.[62] Some Russian experts, however, have indicated that the Globus II X-band radar in Vardo, Norway, which is much closer to Russia, also could be utilized in missile defense operations against Russia.[63] These Russian experts claim that the Norwegian radar will begin tracking Russian ICBM flight trajectories 140 seconds after launch.

The interceptors in Poland have no capability to intercept Russian ICBMs with a time delay of 155 seconds. In addition, the following analysis and figures show that even with a time delay of 120 seconds, Aegis ships located in the North and Barents Seas will not be able to kinematically reach Russian ICBMs (Case XX, Figure 4.5).

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of the American Physical Society Study Group on Boost-Phase Intercept Systems for National Missile Defense: Scientific and Technical Issues," *Reviews of Modern Physics*, Vol. 76, No. 3, 2004.

[62] Dean A. Wilkening, "Does Missile Defense in Europe Threaten Russia?" *Survival*, Vol. 54, February-March 2012.

[63] Viktor Ivanovich Yesin and Yevgeniy Vadimovich Savostyanov, "Russian Experts Conclude European BMD Will Have No Significant Effect on RVSN," World News Connection, NTIS, original Russian publication in *Nezavisimoye Voyennoye Obozreniye*, April 13, 2012.

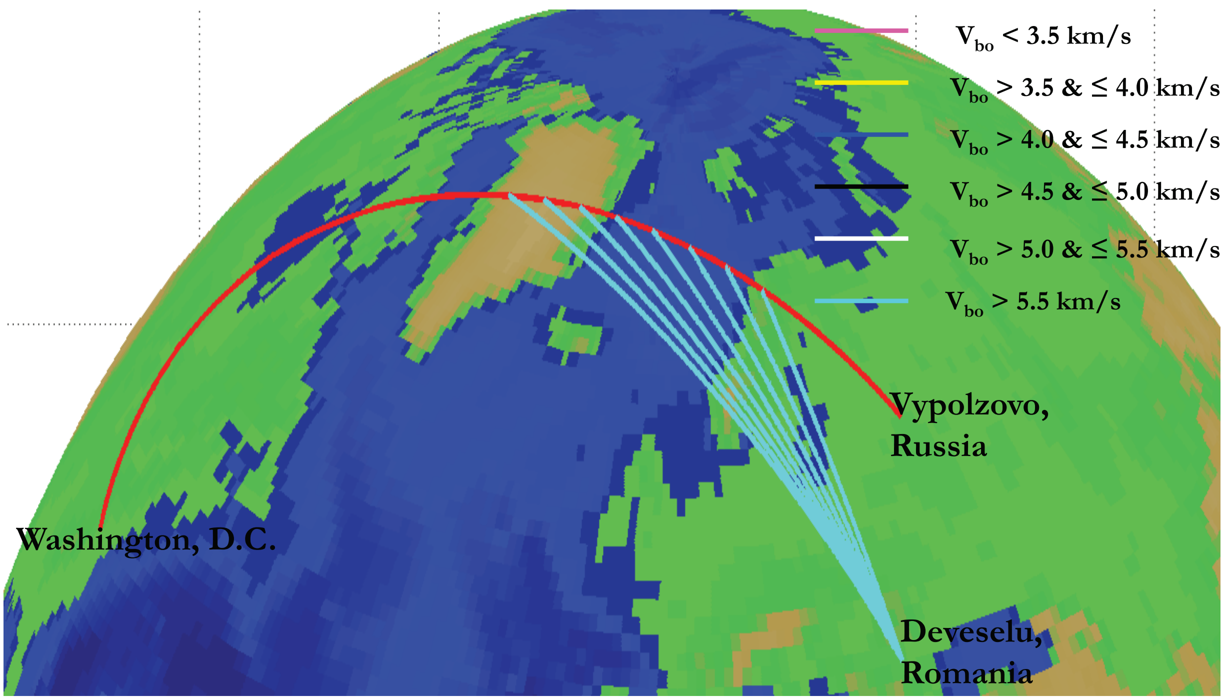
Case XVI: EPAA SM-3 IB Interceptors at Aegis Ashore Site in Deveselu, Romania, Defending Against Russian ICBMs

EPAA SM-3 IIA interceptors located at the Aegis Ashore site in Deveselu will not be able to kinematically reach Russian ICBMs from any of its launch sites, even under an unrealistic zero-time-delay condition, as shown in Figure 4.1.

Figure 4.1. Defending Against a Russian ICBM Attack on Washington, D.C., from Deveselu, Romania

Offense: Russian ICBM missile attack from Vypolzovo, Russia, to Washington, D.C.

Defense: From Aegis Ashore SM-3 IB (V_{bo} = 3.5 km/s) located in Deveselu, Romania



ASSUMPTIONS: (1) Perfect tracking information, (2) minimum energy trajectory, and (3) no countermeasures

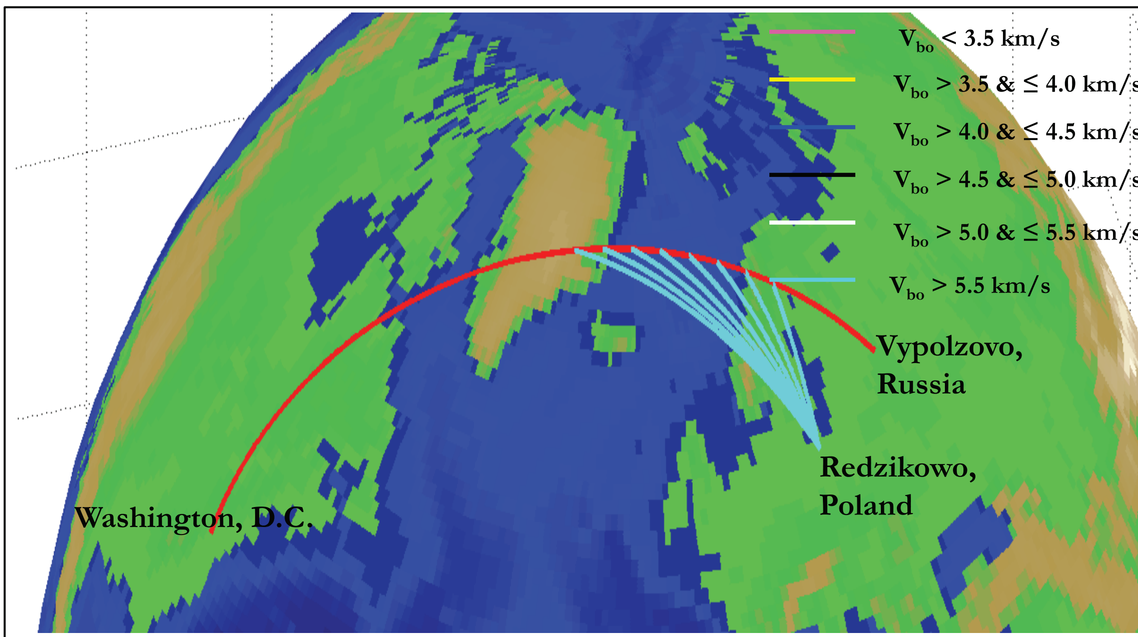
Case XVII: EPAA SM-3 IB Interceptors at Aegis Ashore Site in Redzikowo, Poland, Defending Against Russian ICBMs

EPAA SM-3 IIA interceptors located at the Aegis Ashore site in Redzikowo will not be able to kinematically reach Russian ICBMs from most launch sites, even under an unrealistic zero-time-delay condition. As shown in Figure 4.2, to intercept a Russian ICBM traveling from Vypolzovo to Washington, D.C., requires an interceptor with a burnout velocity greater than 5.5 km/s. Only ICBMs launched from Kozelsk and Tatishchevo are vulnerable to interception under a zero-time-delay condition, and only when they are heading toward Washington, D.C.

Figure 4.2. Defending Against a Russian ICBM Attack on Washington, D.C., from Redzikowo, Poland

Offense: Russian ICBM missile attack from Vypolzovo, Russia, to Washington, D.C.

Defense: From Aegis Ashore SM-3 IIA (V_{bo} = 4.5 km/s) located in Redzikowo, Poland



ASSUMPTIONS: (1) Perfect tracking information, (2) minimum energy trajectory, and (3) no countermeasures

Case XVIII: EPAA SM-3 IB Interceptors on Aegis Ships in the North Sea Defending Against Russian ICBMs

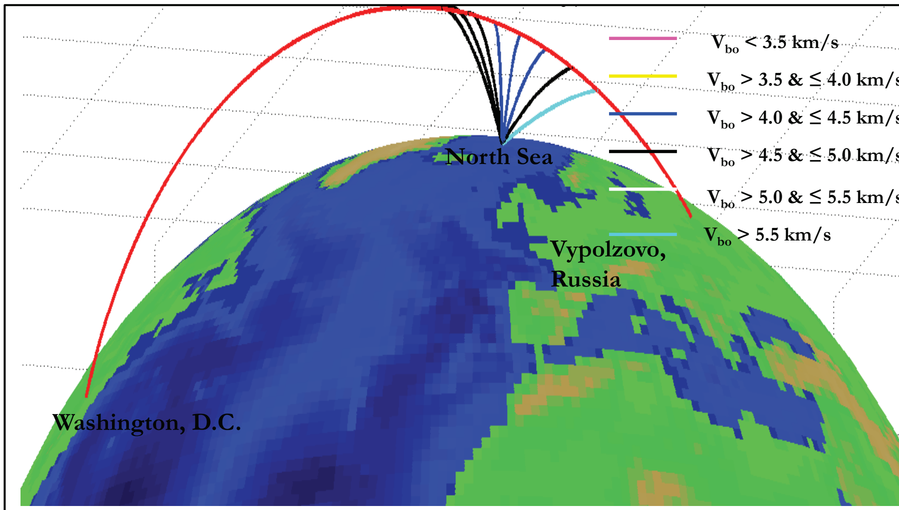
As shown in the central image of Figure 4.3, EPAA SM-3 IIA interceptors on Aegis ships located at a given latitude and longitude point in the North Sea are able to intercept Russian ICBMs traveling from Vypolzovo to Washington, D.C., under zero-time-delay conditions. The last image of Figure 4.3 shows that the EPAA SM3-IIA interceptors on Aegis ships are also able to intercept the same trajectory from a wide region in the North Sea under the same zero-time-delay condition.

However, to reach ICBMs launched from western sites in Russia toward the West Coast of the United States would require Aegis ships located in the Barents Sea.

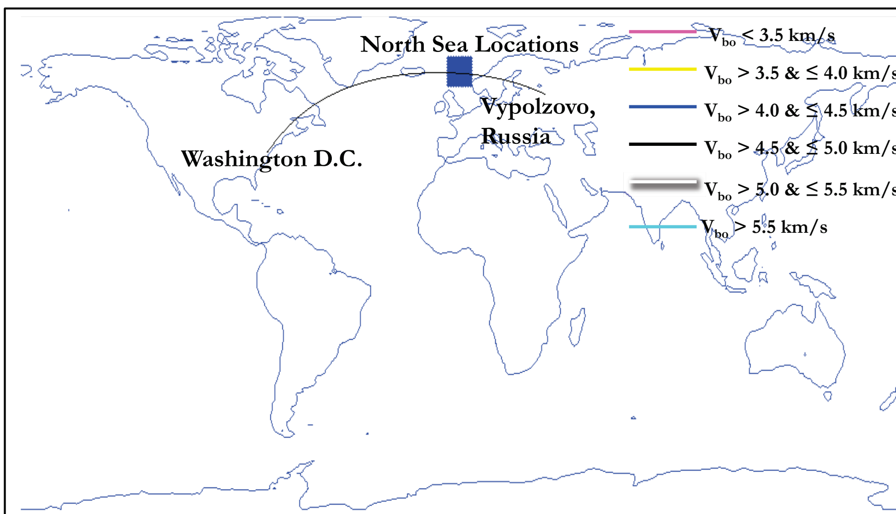
Figure 4.3. Defending Against a Russian ICBM Attack on Washington, D.C., from Aegis Ships in the North Sea

Offense: Russian ICBM missile attack from Vypolzovo, Russia, to Washington, D.C.

Defense: From ship-based SM-3 IIA (V_{bo} = 4.5 km/s) located in the North Sea Area



ASSUMPTIONS: (1) Perfect tracking information, (2) minimum energy trajectory, and (3) no countermeasures



ASSUMPTIONS: (1) Perfect tracking information, (2) minimum energy trajectory, and (3) no countermeasures

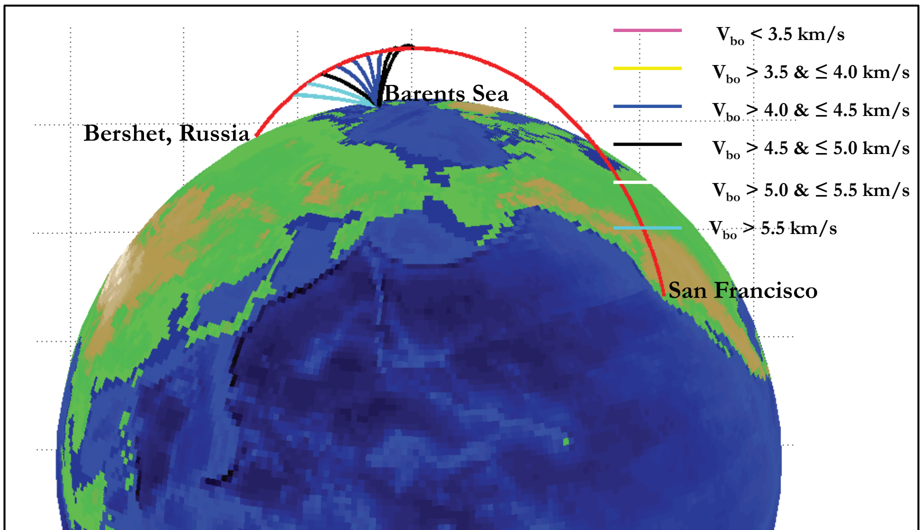
Case XIX: EPAA SM-3 IB Interceptors on Aegis Ships in the Barents Sea Defending Against Russian ICBMs

As shown in the central image of Figure 4.4, EPAA SM-3 IIA interceptors on Aegis ships located at a given latitude and longitude point in the Barents Sea are able to intercept Russian ICBMs traveling from Bershet, Russia, to San Francisco under a zero-time-delay condition. The last image of Figure 4.4 shows that the EPAA SM3-IIA interceptors on Aegis ships are also able to intercept the same trajectory from a wide region in the Barents Sea under the same zero-time-delay condition.

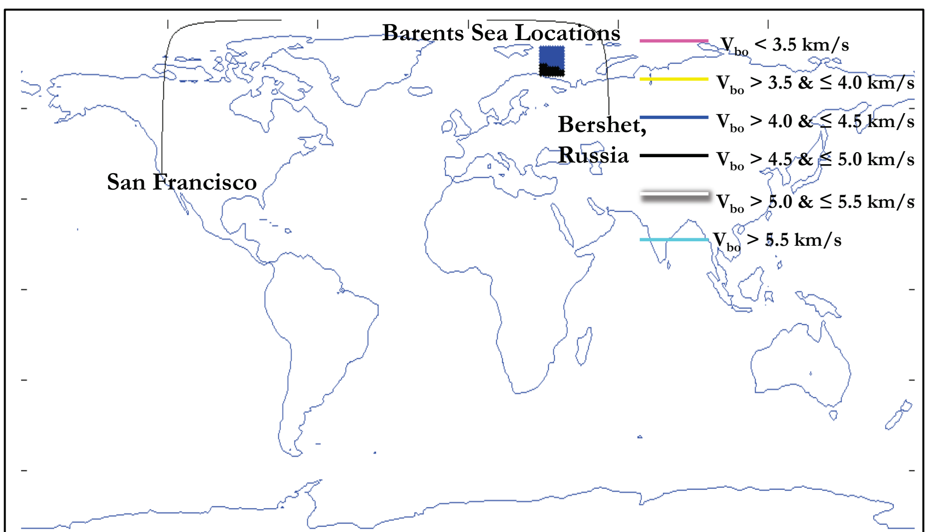
Figure 4.4. Defending Against a Russian ICBM Attack on San Francisco from Aegis Ships in the Barents Sea

Offense: Russian ICBM Missile Attack from Bershet, Russia, to San Francisco

Defense: From ship-based SM-3 IIA (V_{bo} = 4.5 km/s) located in the Barents Sea Area



ASSUMPTIONS: (1) Perfect tracking information, (2) minimum energy trajectory, and (3) no countermeasures



ASSUMPTIONS: (1) Perfect tracking information, (2) minimum energy trajectory, and (3) no countermeasures

Case XX: EPAA SM-3 IB Interceptors on Aegis Ships in the North Sea and Barents Sea Defending Against Russian ICBMs

EPAA SM-3 IIA interceptors on Aegis ships located in the North Sea and Barents Sea will be able to kinematically reach most Russian ICBMs heading to both the East and West coasts of the United States under an ideal zero-time-delay condition. Figure 4.5 depicts ICBM sites that can be reached in dark blue. Only trajectories from the three easternmost missile fields would not be covered. However, that capability disappears at a time delay of 120 seconds. Figure 4.6 shows that the same ICBM sites now require interceptors with a burnout velocity greater than 4.5 km/s (indicated in the black circle). Therefore, they will not be able to intercept Russian ICBMs under a more realistic 155-second time delay without the now-canceled Phase 4 SM-3 IIB interceptors.

Figure 4.5. Defending Against a Russian ICBM Attack on the United States from Aegis Ships in Both the North Sea and Barents Sea (zero time delay)

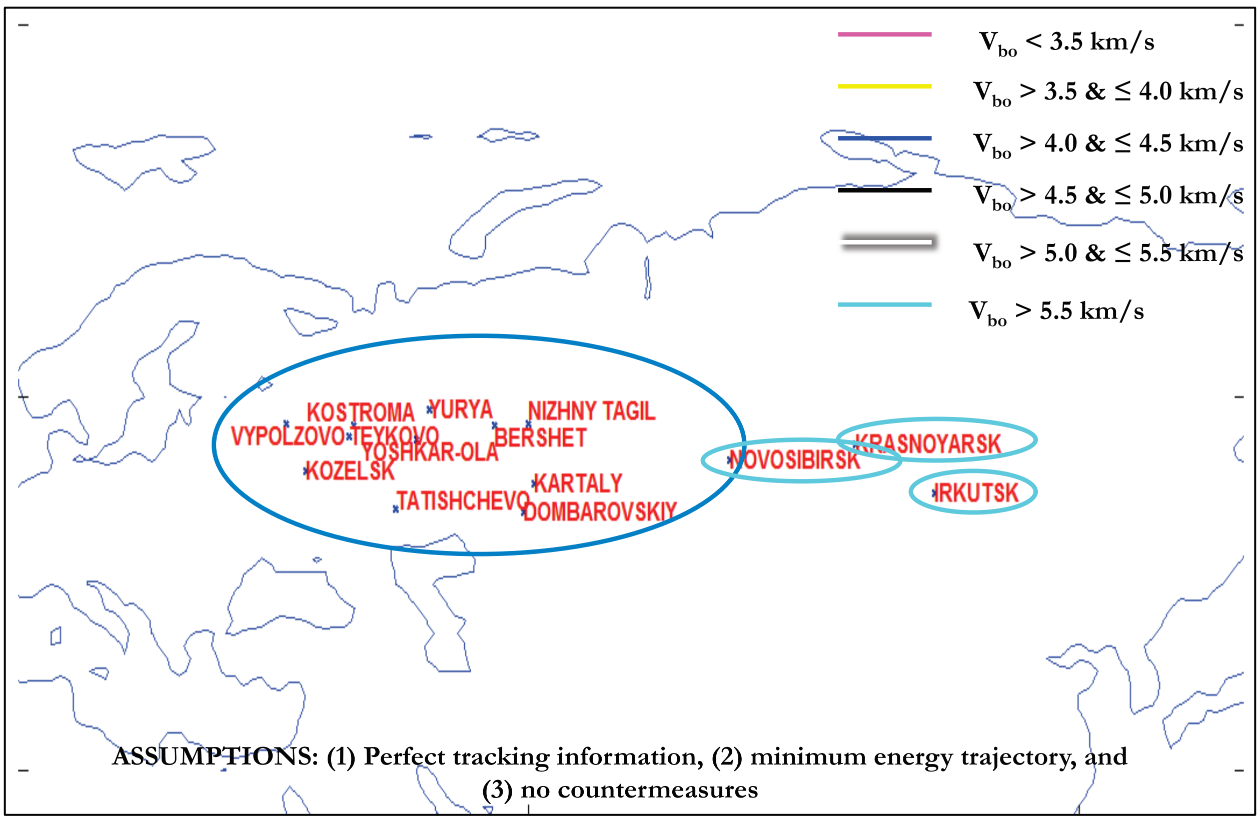
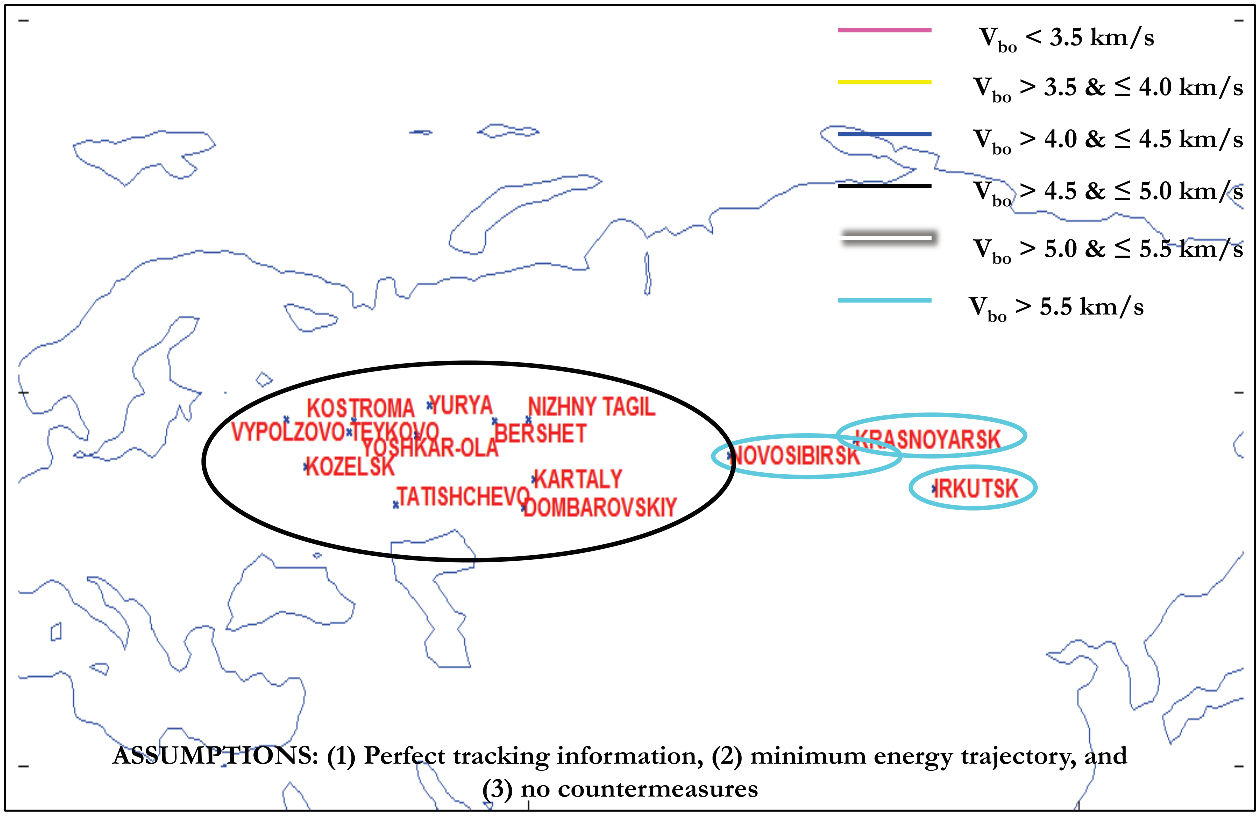


Figure 4.6. Defending Against a Russian ICBM Attack on the United States from Aegis Ships in Both the North Sea and Barents Sea (120-second time delay)



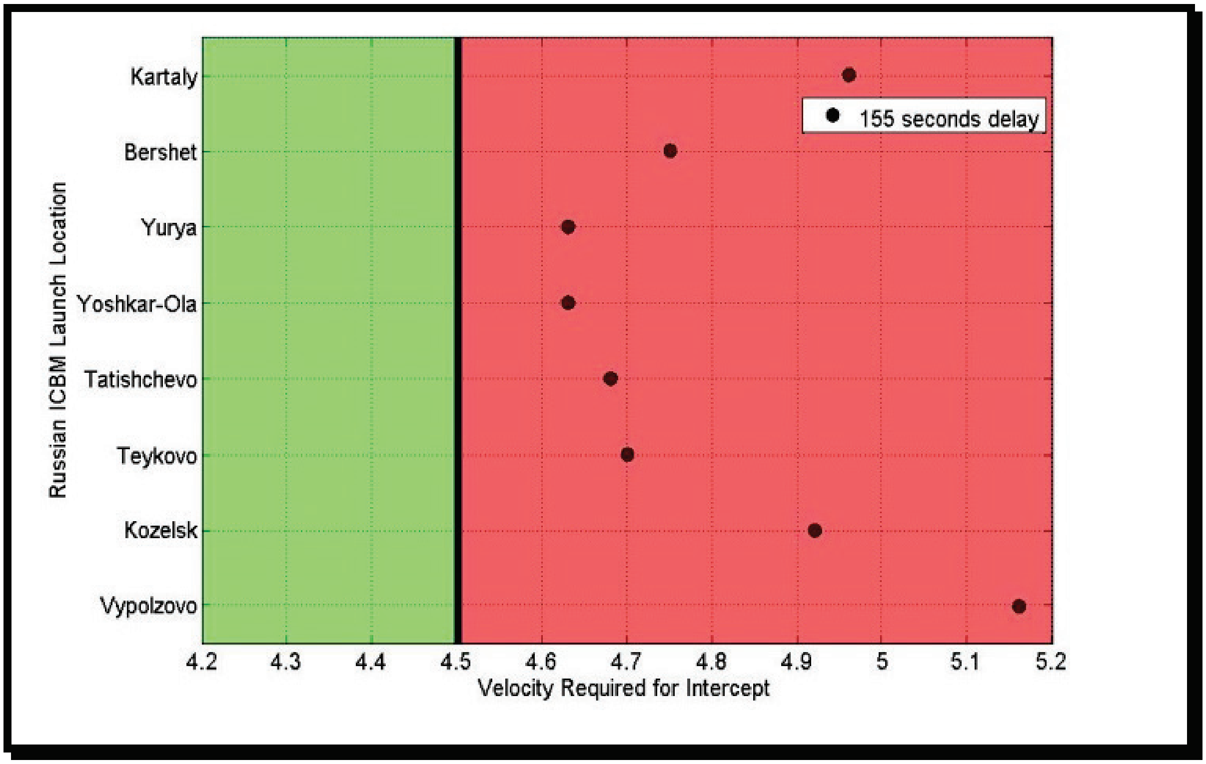
5. Conclusion

Chapters 3 and 4 outlined in detail the technical basis for making an *a fortiori* argument that the restructured EPAA missile defense system would not dilute Russia's deterrent. Some experts within Russia support this argument. In a number of articles, these experts have said that in a hypothetical strike against U.S. territory, Russian ICBMs cannot under any circumstances end up within reach of the missile defense in Romania. They also note that only ICBMs from Kozelsk in western Russia can be intercepted by the missile defense in Poland, but even they do so only if they are aiming for the U.S. East Coast. Furthermore, these experts have said that other missile divisions in western Russia (such as Vypolzovo, Teykovo, Tatishchevo, Yoshkar-Ola, and Dombarovskiy) could possibly be threatened only by ship-based missile defense from waters of the Baltic, Barents, and Norwegian seas. However, the farther east the Russian missile division is located, the more hypothetical this threat becomes. According to these Russian analysts, inasmuch as it is the midcourse, or space, phase of ICBM trajectories that will pass over those seas, even the ship-based missile defense systems are incapable of reaching these missiles in current form.[64]

In fact, this is borne out in the analysis and discussion in Chapter 4. If we extend the work from that chapter further by using the same simulation process outlined in Chapter 3, we can demonstrate that the velocities needed for interceptors based on Aegis ships in the North Sea and Barents Sea to reach Russian ICBMs launched from a number of sites inside Russia are higher than the maximum 4.5 km/s attainable by the SM-3 IIA interceptors under the restructured EPAA system (see Figure 5.1).

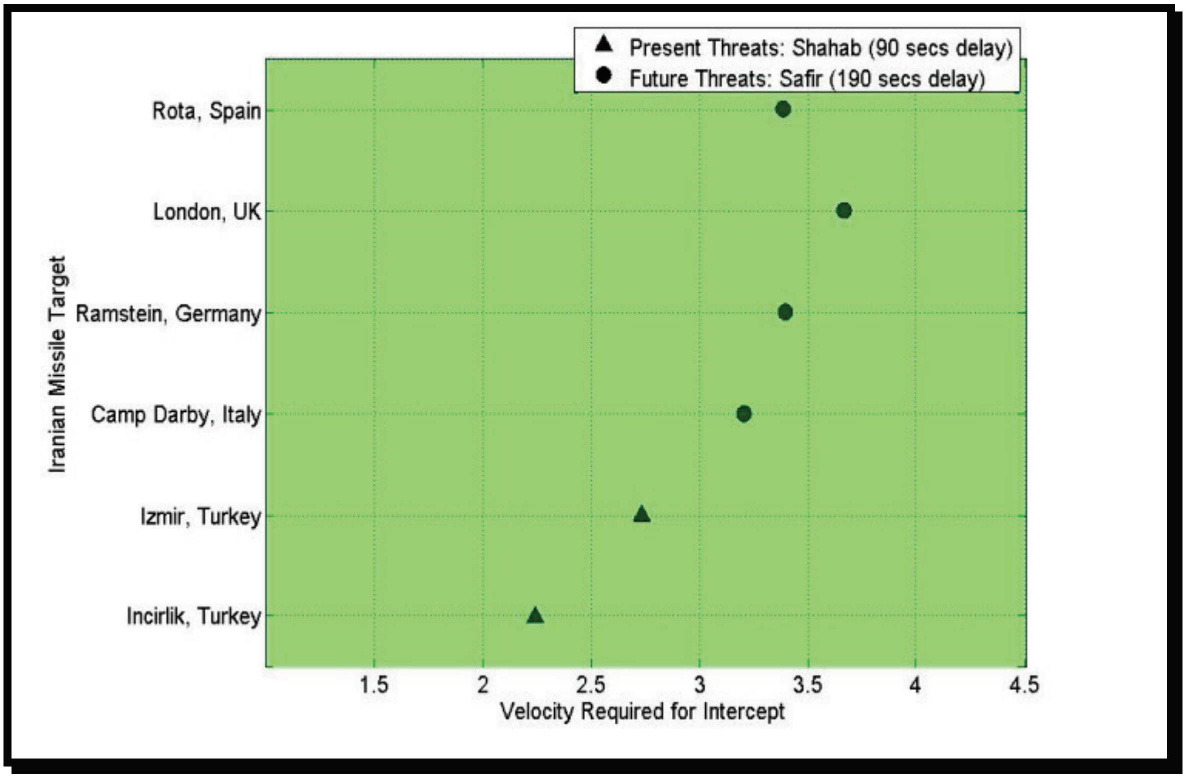
[64] For details, see Khramchikhin (2011) and Yesin and Savostyanov (2012).

Figure 5.1. Interceptor Velocity Needed to Defend Against Russian ICBM Threats from Aegis Ships in the North Sea and Barents Sea



Similarly, it can be demonstrated that the restructured EPAA missile defense system would still be able to kinematically reach an array of current and future Iranian missile threats. This is true even if we factor in a comfortable amount of time for detecting and tracking the missiles. Figure 5.2 shows that the interceptor velocity needed to kinematically reach an Iranian missile from one of the three possible SM-3 basing locations (the Mediterranean Sea, Deveselu, and Redzikowo) is below the maximum interceptor velocity of 4.5 km/s.

Figure 5.2. Interceptor Velocity Needed to Defend Against Iranian Threats



It might still be useful, however, to reassure Russia about the future evolution of U.S. missile defense systems. Giving Russia access to interceptor data, such as burnout velocity, is one of the prominent suggestions.[65] Given the now-reduced maximum velocity of the current system, however, it is not clear what data the United States could provide to the Russians that they could not discern on their own and that would provide them with a greater reassurance about the capabilities of the interceptors deployed under the phased adaptive approach. Russia possesses, among other means, its own early-warning satellites and radars that it can use to monitor and estimate the characteristics of interceptors deployed under the phased adaptive approach.[66] Also, as described above, even under ideal conditions, the currently planned U.S.-NATO system does not pose any potential threat to Russia. Additional data are not needed to determine this.

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[65] Wolf, 2012.

[66] For example, Russian radars detected the recent Israeli test-firing of the Sparrow missile in September 2013. The Sparrow, which simulates the long-range missiles of Syria and Iran, is used for target practice by Israel's U.S.-backed ballistic shield, Arrow. Available public information suggests that Russia was able to determine launch location and flight direction. Given this, it is reasonable to conclude that Russia would also be able to monitor and estimate the velocity of the SM-3 interceptors independently. For a review of current Russian early-warning satellites and radars, see Russian Strategic Nuclear Forces, "Early Warning," September 9, 2013. For details on the detection of the Israeli missile launch, see Dan Williams and Steve Gutterman, "Unannounced Israel-U.S. Missile Test Fuels Jitters over Syria," Reuters, September 3, 2013.

However, the United States could bolster the offer of a political agreement by emphasizing the possibility of developing a joint U.S.-Russian data exchange center focused on monitoring missile launches. It might help demonstrate to Russia the limitations of current U.S. early-warning and missile tracking systems.[67]

The decision by the Obama administration to eliminate SM3-IIB interceptors, the fourth phase of the EPAA missile defense system, has effectively removed any possibility that the system could be a threat to Russian ICBMs. This policy action has created an opening for the United States and Russia to come together on bilateral measures. Both nations should utilize this window and move forward on their arms reduction goals.

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[67] Steven Pifer, "NATO-Russia Missile Defense: Compromise Is Possible," Brookings Institution, December 2012.

References

Arms Control Association, "The European Phased Adaptive Approach at a Glance," Washington, D.C., May 2013. As of January 7, 2015: http://www.armscontrol.org/factsheets/Phasedadaptiveapproach

Associated Press, "U.S. Changes in Missile Defense Plan May Provide Opening for New Arms-Control Talks with Russia," March 17, 2013. As of January 7, 2015: http://www.foxnews.com/us/2013/03/16/us-changes-in-missile-defense-plan-may-provide-opening-for-new-arms-control/

Balakrishnan, Angela, "Barack Obama Calls for Tougher Iran Sanctions After Missile Tests," *The Guardian*, July 9, 2008. As of January 7, 2015: http://www.theguardian.com/world/2008/jul/09/iran.usa

Barnes, Julian E., and Megan K. Stack, "Russia's Putin Praises Obama's Missile Defense Decision," *Los Angeles Times*, September 19, 2009. As of January 7, 2015: http://articles.latimes.com/2009/sep/19/world/fg-missile-defense19

Barton, David K., Roger Falcone, Daniel Kleppner, Frederick K. Lamb, Ming K. Lau, Harvey L. Lynch, David Moncton, David Montague, David E. Mosher, William Priedhorsky, Maury Tigner, and David R. Vaughan, "Report of the American Physical Society Study Group on Boost-Phase Intercept Systems for National Missile Defense: Scientific and Technical Issues," *Reviews of Modern Physics*, Vol. 76, No. 3, 2004.

Bate, Roger R., Donald D. Mueller, and Jerry E. White, "Fundamentals of Astrodynamics," New York: Dover Publications, Inc., 1971.

Boyer, Dave, "Obama Defends Russia 'Reset' Despite Strained Ties with Putin," *Washington Times*, September 4, 2013. As of January 7, 2015: http://www.washingtontimes.com/news/2013/sep/4/obama-defends-russia-reset-despite-strained-ties-p/

Bridge, Robert, "Moscow Looking for NATO Cooperation, Missile Defense Guarantees," RT News, February 19, 2013. As of January 7, 2015: http://rt.com/politics/russia-missile-defense-nato-security-document-566/

Bruno, Greg, "Iran's Ballistic Missile Program," Council on Foreign Relations, July 23, 2012. As of January 7, 2015: http://www.cfr.org/iran/irans-ballistic-missile-program/p20425

Calabresi, Massimo, "Behind Bush's Missile Defense Push," *Time*, June 5, 2007. As of January 7, 2015: http://content.time.com/time/nation/article/0,8599,1628289,00.html

Clapper, James R., Director of National Intelligence, "Unclassified Statement for the Record on the Worldwide Threat Assessment of the U.S. Intelligence Community for the Senate Select Committee on Intelligence," Washington D.C., January 31, 2012.

Coalson, Robert, "European Missile Defense: What's on the Table at NATO Summit?" Radio Free Europe/Radio Library, May 19, 2012. As of January 7, 2014: http://www.rferl.org/content/european-missile-defense-explainer/24586198.html

Collina, Tom Z., Daryll Kimball, and Greg Thielmann, "What Does DOD's Missile Defense Announcement Mean?" *Arms Control Now*, March 15, 2013.

Congressional Budget Office, *Options for Deploying Missile Defenses in Europe*, February 2009. As of January 7, 2015: http://www.cbo.gov/sites/default/files/02-27-missiledefense.pdf

Crail, Peter, "Iran Launches Second Satellite," *Arms Control Today*, July/August 2011. As of January 7, 2015: https://www.armscontrol.org/act/2011_%2007-08/%20Iran_Launches_Second_Satellite_Safir_Rasad

Dilanian, Ken, "Obama Scraps Bush Missile-Defense Plan," *USA Today*, 2009. As of January 7, 2015: http://abcnews.go.com/Politics/obama-scraps-bush-missile-defense-plan/story?id=8604357&singlePage=true

Dougherty, Jill, "Clinton 'Reset Button' Gift to Russian FM Gets Lost in Translation," CNN, March 6, 2009. As of January 7, 2015: http://politicalticker.blogs.cnn.com/2009/03/06/clinton-reset-button-gift-to-russian-fm-gets-lost-in-translation/

Fiddan, Paul, "Iran's Great Prophet VIII Military Exercise," Armed Forces International, February 20, 2013. As of January 7, 2014: http://www.armedforces-int.com/news/irans-great-prophet-viii-military-exercise.html

Hecker, Siegfried S., and David Holloway, *Iran's Nuclear and Missile Potential: A Joint Threat Assessment by U.S. and Russian Technical Experts*, EastWest Institute, May 2009.

Hildrith, Steven A., "Iran's Ballistic Missile and Space Launch Programs," Congressional Research Service, December 6, 2012.

Hoskinson, Charles, "Gap Widens over Missile System," *Politico*, September 14, 2011.

International Atomic Energy Agency, "Implementation of the NPT Safeguards Agreement and Relevant Provisions of Security Council Resolutions 1737 (2006), 1747 (2007), 1803 (2008) and 1835 (2008) in the Islamic Republic of Iran," GOV/2010/10, 2010, para 41.

International Institute for Strategic Studies, "Iran's Ballistic Missile Capabilities: A Net Assessment," Strategic Dossier, May 7, 2010.

"Iran Boasts It Could Wipe Out U.S. Presence in Middle East in Minutes," RT News, July 4, 2012. As of January 7, 2015: http://rt.com/news/iran-great-prophet-hormuz-us-bases-416/

"Iran Doctored Missile Test-Firing Photo: Defence Analyst," *The Gazette,* CanWest MediaWorks Publications, July 10, 2008. As of January 7, 2015: http://www.canada.com/story.html?id=dec1c7a5-0af3-4098-98a9-ffce70cb4d7e#__federated=1

Isayev, Trend S., and T. Jafarov, "Iran to Hold 'Great Prophet VIII' Military Exercises," Trend News Agency, February 20, 2013. As of January 7, 2015: http://en.trend.az/regions/iran/2121759.html

Itzkowitz Shifrinson, Joshua R., and Miranda Priebe, "A Crude Threat: The Limits of an Iranian Missile Campaign Against Saudi Arabian Oil," *International Security*, Vol. 36, No. 1, Summer 2011, pp. 167–201.

Khramchikhin, Aleksandr, "Russia: Khramchikhin Answers Criticism of His Earlier Article on Missile Defense," World News Connection, NTIS, original Russian publication in *Nezavisimoye Voyennoye Obozreniye*, July 22, 2011.

Levy, Clifford J., and Peter Baker, "Russia's Reaction on Missile Defense Plan Leaves Iran Issue Hanging," *New York Times*, September 18, 2009. As of January 7, 2015: http://www.nytimes.com/2009/09/19/world/europe/19shield.html?_r=0

Marshall, Eliot, "A Midcourse Correction for U.S. Missile Defense System," *Science*, Vol. 339, March 29, 2013.

"Moscow Takes Harder Line, but NATO Chief Still 'Hopeful' on Missile Defense," Radio Free Europe/Radio Library, May 3, 2012. As of January 7, 2015: http://www.rferl.org/content/russia_nato_missile_defense_talks_at_dead_end/24568278.html

National Air and Space Intelligence Center, *Ballistic and Cruise Missile Threat*, U.S. Air Force, Wright-Patterson Air Force Base, Ohio, 2013. As of January 7, 2015: http://www.25af.af.mil/shared/media/document/AFD-130710-054.pdf

Nizza, Mike, and Patrick J. Lyons, "In an Iranian Image, A Missile Too Many," *New York Times*, July 10, 2008.

"'No Flexibility' in US Missile Talk—Medvedev," Sputnik News, January 27, 2013. As of January 7, 2015: http://en.rian.ru/russia/20130127/179063928.html

Nuclear Threat Initiative, "Russia Restates Demand for Pledge on NATO Missile Shield," September 14, 2011. As of January 7, 2015: http://www.nti.org/gsn/article/russia-restates-demand-for-pledge-on-nato-missile-shield/

———, "New Russian Nuke Cuts Will Depend on U.S. Missile Defense Moves: Putin," Washington, D.C., August 24, 2012a. As of January 7, 2015; http://www.nti.org/gsn/article/new-russian-nuke-arsenal-cuts-will-depend-us-missile-defense-putin/

———, "Russia Warns U.S. Against Deploying Final Phases of Missile Shield," October 1, 2012b. As of January 7, 2015: http://www.nti.org/gsn/article/russia-warns-us-against-implementing-last-phases-missile-shield/

"Obama's Missile Defense: It's Better These Days to Be a U.S. Adversary Than Its Friend," *Wall Street Journal,* September 18, 2009. As of January 7 , 2015: http://online.wsj.com/news/articles/SB10001424052970204518504574418563346840666

O'Rourke, Ronald, *Navy Aegis Ballistic Missile Defense (BMD) Program: Background and Issues for Congress*, Congressional Research Service, November 7, 2014.

Oswald, Rachel, "U.S. Official: 'Not Making Much Progress' With Russia on Missiles, Arms," Global Security Newswire, November 13, 2013. As of January 7, 2015: http://www.defenseone.com/politics/2013/11/us-official-not-making-much-progress-russia-missiles-arms/73772/

Pifer, Steven, "NATO-Russia Missile Defense: Compromise Is Possible," Brookings Institution, December 2012.

———, "U.S.-Russian Arms Control in the Absence of a Summit," Brookings Institution, September 4, 2013. As of January 7, 2015: http://www.brookings.edu/research/opinions/2013/09/04-us-russian-arms-control-in-absence-of-summit

"Remarks by the President on Strengthening Missile Defense in Europe," White House Office of the Press Secretary, September 17, 2009. As of January 7, 2015: http://www.whitehouse.gov/the_press_office/Remarks-by-the-President-on-Strengthening-Missile-Defense-in-Europe

Reynolds, Paul, "Iran's Slow but Sure Missile Advance," BBC News, February 3, 2009. As of January 7, 2015: http://news.bbc.co.uk/2/hi/middle_east/7866742.stm

Rogov, Sergey, Viktor Yesin, Pavel Zolotarev, and Valentin Kuznetsov, "Russia: Experts – Missile Defense Compromise Dependent on Obama Reelection," World News Connection, NTIS, original Russian publication in *Nezavisimoye Voyennoye Obozreniye*, September 20, 2012.

Rose, Frank R., Deputy Assistant Secretary, Bureau of Arms Control, Verification, and Compliance, "Reinforcing Stability Through Missile Defense," remarks made at the Organization for Security and Co-operation in Europe's Forum for Security Co-Operation, Vienna, Austria, June 6, 2012a.

———, Deputy Assistant Secretary, Bureau of Arms Control, Verification, and Compliance, "Growing Global Cooperation on Missile Defense," address delivered at the 2012 Multinational Ballistic Missile Defense Conference and Exhibition, Berlin, Space News, October 1, 2012b.

Russian Strategic Nuclear Forces, "Early Warning," September 9, 2013. As of January 7, 2015: http://russianforces.org/sprn/

Sankaran, Jaganath, "Missile Defense Against Iran Without Threatening Russia," *Arms Control Today*, November 2013.

Shanker, Thom, "Moscow Perplexes U.S. over Missile Defense in Europe," *New York Times*, February 21, 2007. As of January 7, 2015; http://www.nytimes.com/2007/02/21/world/europe/21iht-policy.4675904.html?pagewanted=all

Singh, Michael, "Iran Threatens Gulf Blitz If U.S. Hits Nuclear Plants," *Sunday Times*, June 10, 2007.

Tauscher, Ellen, U.S. Department of Defense Special Envoy for Strategic Stability and Missile Defense, "Ballistic Missile Defense: Progress and Prospects," remarks made at the Tenth Annual Missile Defense Conference, Washington D.C., March 26, 2012.

Topychkanov, Peter, "Missile Defense: Not Joint, but Cooperative," Russia Beyond the Headlines, June 24, 2011. As of January 7, 2015: http://rbth.ru/articles/2011/06/24/missile_defense_not_joint_but_cooperative_13083.html

U.S. Department of Defense, *Annual Report on Military Power of Iran*, April 2012, p. 4.

Vallado, David A., "Fundamentals of Astrodynamics and Applications," New York: McGraw-Hill Companies, 1997

Whitelaw, Kevin, "Obama's Missile Plan Decision: What It Means," National Public Radio*,* September 17, 2009. As of January 7, 2015: http://www.npr.org/templates/story/story.php?storyId=112909735

Wilkening, Dean A., "Does Missile Defense in Europe Threaten Russia?" *Survival*, Vol. 54, February-March 2012.

Williams, Dan, and Steve Gutterman, "Unannounced Israel-U.S. Missile Test Fuels Jitters over Syria," Reuters, September 3, 2013. As of January 7, 2015: http://www.reuters.com/article/2013/09/03/us-syria-crisis-russia-defence-idUSBRE9820AC20130903

Wolf, Jim, "Exclusive: U.S. Dangles Secret Data for Russia Missile Shield Approval," Reuters, March 13, 2012. As of January 7, 2014: http://www.reuters.com/article/2012/03/14/us-usa-russia-missiledefense-idUSBRE82D03A20120314

"World in Brief," *Washington Post*, September 10, 2006, p. A23.

Yesin, Viktor Ivanovich, and Yevgeniy Vadimovich Savostyanov, "Russian Experts Conclude European BMD Will Have No Significant Effect on RVSN," World News Connection, NTIS, original Russian publication in *Nezavisimoye Voyennoye Obozreniye*, April 13, 2012.